AN ABSTRACT OF THE DISSERTATION OF

David H. Demaree for the degree of Doctor of Philosophy in Environmental Science presented on June 11, 2020.

Title: Nitrate derived from Onsite Wastewater Treatment Systems (NOWTS): A Study of Public Perceptions, Politics, and Perpetual Permitting in the Western US

Abstract approved:

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Onsite wastewater treatment systems (OWTS; septic systems, compost toilets, etc.) used to treat wastewater in rural areas have the potential to contaminate groundwater (that is used as a water source) with nitrate. There have been decades of scientific and political conflicts concerning the issue of nitrate from OWTS (NOWTS, pronounced "knots") in the communities of La Pine, Oregon and Laramie, Wyoming. This dissertation explores the science and policy of NOWTS conflicts to determine how decision-makers, experts, consultants, residents, stakeholders, and the author affect, and are affected by, the NOWTS conflicts.

This dissertation explores the conflicts in La Pine and Laramie through four chapters. Chapter two is a soil study conducted in La Pine to determine how much nitrate from septic systems reaches the water table. The soil study found that there was more nitrate in soils at residences with septic systems than in other areas, but due to the limitations of the study, the source of the nitrate was uncertain. The HYDRUS model was used to simulate nitrate transport from septic systems and found that

nitrate concentrations are reduced by 24-40% by the time septic water reaches the water table in La Pine.

Chapter three analyzes how stakeholders were affected by the history and the geographic setting of conflicts in La Pine and Laramie. Information was collected from surveys in La Pine, interviews in Laramie, and documentation of the conflicts from both locations. Geographically, it was found that stakeholders in La Pine and Laramie were split along the urban-rural divide. From the history, stakeholders became more knowledgeable of the conflict, created opinions of other stakeholders that colored interactions, and were fatigued by the conflicts.

Chapter four explores the role of government experts, consultants, and academics (GAC experts) in these conflicts through five controversial studies in La Pine and Laramie. It was found that miscommunications occurred between GAC experts and stakeholders that escalated conflicts. Miscommunications included: The role experts were supposed to play in the conflict; GAC experts' language and mannerisms, such as dumping too much information on stakeholder at one time; Study limitations and external factors also prevented experts from sufficiently addressing stakeholder questions and concerns.

Chapter five studies the role of science created by residents (resident science) in La Pine and Laramie. Some residents have high educational attainments and are professionals in water resources related fields and conducted resident science independently or with the support of non-governmental organizations. Factors that led to the creation of resident science included mistrust between residents and experts, residents noticing data gaps or having unanswered questions, and stakeholders having the resources necessary for resident science. Though controversial in La Pine and Laramie, resident science was accepted enough that it was part of the conflict dialog and affected policies.

The conclusion summarizes the findings from the previous chapters and provides policy recommendations and recommendations for future NOWTS studies. The policy recommendations include involving more groups and expanding the scope of the conflict to increase the pool of resources and add flexibility to the conflict. Another is to leverage small cooperative projects between multiple groups to build trust and political momentum for larger actions. Science recommendations focus on ways for experts to collaborate with stakeholders to assuage conflict. Both the science and policy issues need to be addressed in order to move forward on NOWTS conflict.

Nitrate derived from Onsite Wastewater Treatment Systems (NOWTS): A Study of Public Perceptions, Politics, and Perpetual Permitting in the Western US

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

David H. Demaree, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

Figure | Page

LIST OF TABLES

LIST OF APPENDICES

DEDICATION

I dedicate this to everyone dealing with ‘wicked’ problems; where stakeholder arguments are both technically true and technically false; where there is no easy solution and we all have to wade through the quagmire.

1. GENERAL INTRODUCTION

Nitrate contamination of groundwater has been an environmental and human health issue since 1945, when methemoglobinemia in infants was attributed to nitrate from well water (Comly, 1945). There has been growing concern in the United States of America (US) over nitrate contamination in drinking water and groundwater since the Safe Drinking Water Act (SDWA) in 1974 and the Wellhead Protection Amendment in 1986. Under the SDWA, the US Environmental Protection Agency (EPA) set a drinking water standard of 10 mg/L of nitrate (concentration based on weight of nitrogen in nitrate) in drinking water from surface waters and groundwater wells that serve more than 25 people.

In many rural communities in the Western US, private wells are the only source of potable water, and conventional septic systems are the main type of onsite wastewater treatment system (OWTS). In these rural communities, nitrate from onsite wastewater treatment systems (NOWTS, pronounced "knots") has been viewed as a potential contaminant for groundwater used as a drinking water source. Over time, NOWTS has come under increased scrutiny by regulators and policymakers as rural areas became more developed and wells were found with elevated nitrate concentrations (Rich, 2005).

NOWTS falls in a legal and regulatory gray area. Federal water quality laws do not apply to most private domestic wells since the wells serve fewer than 25 people. Few states have water quality regulations on private wells, and the decision regarding acceptability as a drinking water supply for private wells is with the well owner.

States, counties, and cities address NOWTS locally using a variety of regulatory strategies (Appendix B). The NOWTS regulations often create conflicts between regulators and residents. Regulators want to protect residents from nitrate by having private wells meet public drinking water standards. Residents oppose the regulatory changes for many reasons, including restrictions on property rights, the financial cost of regulations for property owners, and limits to the control well owners have over their wells. There are also disagreements over how much of an issue NOWTS is and what its potential impacts may be. Residents often disagree with regulators over the impacts of NOWTS because the science of NOWTS is complex and varies depending on local conditions (McLaren, 1976; Hofstra and Bouwman, 2005). Additionally, there are often dueling experts on the sides of both regulators and residents.

These factors make NOWTS similar to other 'wicked problems' in natural resources, where there is little stakeholder consensus on the definition of 'the problem' and stakeholders propose many different 'solutions' based on their view of the problem (Rittel and Webber, 1973). In this dissertation, stakeholders include experts, regulators, residents, community groups, and anyone who has an interest in the conflict. The acronym and pronunciation of NOWTS ("knots") was chosen as a metaphor for the complex connections between stakeholders, policy, and science.

NOWTS is like a metaphorical 'knot' composed of many strands (stakeholders, experts, communities, science, etc.…). The goal of this dissertation is to provide a tool (like a fid) to loosen the knot and pick at the strands. This dissertation will not 'solve' NOWTS problems, since NOWTS is complex and will take a greater effort than a single dissertation to solve.

Alexander the Great's solution to the Gordian Knot (either by cutting the knot with a sword or by removing a linchpin) is not recommended, because the strands and linchpin represent institutions, people, and groups that all have a say in our democracy.

1.1 Purpose

The purpose of this dissertation is to better understand the connection between the politics and science of NOWTS conflicts.

This dissertation was motivated by a citizens' action group who reached out to the author because they wanted a third party to conduct a scientific study in La Pine, OR. The citizens' action group reached out because there had been decades of conflict over NOWTS issues in La Pine, and some of the previous NOWTS studies were contentious.

The author first conducted an environmental science investigation of NOWTS in La Pine, OR (Chapter two). All the aspects of the environmental science investigation were adjusted based on politics, permitting, stakeholder views, and conflicts between the author and stakeholders. To better understand how conflicts affected the environmental science investigation in La Pine, the author explored the

NOWTS conflicts in La Pine, OR and Laramie, WY. The conflicts in the two regions were compared to find common themes. The author's hope is that stakeholders and experts will use the information in this dissertation to create less controversial scientific presentations.

The format of this dissertation is intended to be less controversial and was written so that it would be understandable to experts, stakeholders, and people who are new to the dissertation material. This dissertation addresses four research questions. The questions are addressed in summarized format in the body of the dissertation and in longer technical format in the Appendixes A-D. The chapters which cover specific questions standalone (Chapters two though five), while the introduction and conclusion (Chapters one and six) bring all the chapters together.

The specific questions addressed in this dissertation are:

1. How much nitrate from septic systems passes though the vadose zone and reaches groundwater in La Pine, OR?
2. How did the setting and history of the conflicts in La Pine, OR and Laramie, WY affect stakeholders?
3. How did communication barriers between experts and stakeholders affect the conflicts in La Pine, OR and Laramie, WY?
4. Why did residents in La Pine, OR and Laramie, WY start their own science projects? Why was science created by residents widely accepted by stakeholders?

Chapter two focuses on the environmental science investigation of NOWTS in La Pine. The main goal of the investigation was to determine how much nitrate from septic systems passes though unsaturated soils and reaches groundwater in La Pine and to verify the appropriateness of the assumptions used in previous studies (Morgan et al., 2007). Eleven different soil analyses were done to determine which types of analyses were most effective for interpreting of results and for communicating with stakeholders. The analyses were used to create a nitrate transport model for La Pine. Information on nitrate transport from Laramie was used to fill in data gaps in information from La Pine. The data from La Pine and Laramie were also compared to determine the characteristics of nitrate transport that were transferable between locations.

Chapter three looks at how the setting and history of conflicts in La Pine and Laramie affected stakeholders. The setting of a conflict includes the geography, laws, personal relationships, urban-rural divide, culture, expertise, power disparities, and communication that affect the stakeholders in a conflict. The history documents the changes in the conflict setting over time, such as regulatory changes, stakeholder involvement, and stakeholder views. These factors are explored through conflict management tools based on surveys, interviews, and records. Two aspects of the setting and history are explored in greater detail: the role of experts (Chapter four) and the science created by residents (Chapter five).

Chapter four takes a look at the communication barriers between government experts, academics, consultants (GAC experts), and stakeholders (who may be experts) in La Pine and Laramie. In both La Pine and Laramie, stakeholders wanted more scientific data and viewed science as a way to resolve conflict. GAC experts in La Pine and Laramie presented their findings and conducted their studies using standard academic and technical practices. The technical practices used by GAC experts escalated conflicts because stakeholders had many different interpretations of expert findings. GAC expert knowledge was perceived as conflicting with local knowledge, and there was a lack of constructive communication between GAC experts and stakeholders. Communication between GAC experts and stakeholders is analyzed by exploring the impact the studies had on stakeholders, based on surveys, interviews, and records.

Chapter five analyzes two questions: "Why did residents in Laramie, WY and La Pine, OR start their own science projects? Why was science created by residents widely accepted?" "Resident science" is science conducted by residents and experts in their capacity as residents of a community, and the research was not affiliated with or funded by a government or academic institution. In both La Pine and Laramie, resident science was created to build upon the work of expert studies, to fill in data gaps, and to protect the community. The use of resident science was controversial in La Pine and Laramie. Resident science had different levels of legitimacy with different stakeholder groups. However, resident science had enough legitimacy to shape stakeholder perspectives, policies, and science.

Chapter six concludes the dissertation with a synthesis of the previous chapters. The conclusion also proposes recommendations for addressing NOWTS science and policy and provides summary reports of the studies conducted in La Pine and Laramie as examples of potential ways for environmental science experts to better communicate with stakeholders.

1.2 Terms

The terminology for people and groups in this thesis is purposely vague to protect the identity of the people who communicated with the author, and to organize people in a meaningful way.

People do not fit into clearly defined categories. For example, an expert is anyone who has authoritative knowledge of an area. To people communicated with as part of this dissertation, the term expert includes a wide range of people: scientists, engineers, consultants, well installers, septic system professionals, and residents who have decades of experience in NOWTS politics.

People involved in conflicts can have multiple affiliations and their affiliations can change over time. Returning to the term "expert," almost every stakeholder group in La Pine and Laramie has members who are both experts and also members of one or more stakeholder groups. When this dissertation refers to a specific group of experts, either they will be referred to by the group they belong to or there will be a parenthesis after the term experts; for example, expert (resident of the City of Laramie). In Chapter four, the term "GAC expert" is used as a general term for government experts, consultants, or academics.

This dissertation makes the assumption that the terms for the groups will be perceived in the most inclusive way possible. For example, stakeholder refers to anyone who has an interest in an issue and includes experts, government, the public, NGOs, and many other groups. An expert (resident of the City of Laramie) said, "We are all stakeholders." Since all stakeholders have an interest in the issues, this dissertation acknowledges that all stakeholders (including the author) have some level of bias.

Other terms of note are:

Chapter: Refers to a section of the dissertation under the first heading level (ex. 1. GENERAL INTRODUCTION) and work that was conducted for that section.

Dissertation: The entirety of this document, or work that was conducted as part of this document.

Nitrate: Nitrate is the polyatomic ion NO_3^-. When concentration of nitrate is referred to in this dissertation, it is based on the concentration of N atoms in NO_3^-.

Onsite Wastewater Treatment System (OWTS): A general term for any appliance that treats wastewater at or near the same location where the wastewater was created. For example, in the La Pine area:

- Rural residents use conventional septic systems and modified septic systems which have an extra treatment step between the septic tank and leach field that treats wastewater for nitrate.
- Campgrounds often have chemical toilets.
- Other types of systems may also be used, such as compost or incineration.

Septic System: Refers to conventional septic systems which are composed of a septic tank and leach field.

Study/Studies: Refers to scientific work that was conducted by people who are not the author of the dissertation.

1.3 References

Comly, H., 1945, Cyanosis in Infants Caused by Nitrates in Well Water: Journal of the American Medical Association, v. 129, p. 112–116.

Hofstra, N., and Bouwman, A.F., 2005, Denitrification in Agricultural Soils: Summarizing Published Data and Estimating Global Annual Rates: Nutrient Cycling in Agroecosystems, v. 72, p. 267–278, doi:10.1007/s10705-005-3109-y.

McLaren, A.D., 1976, Rate constants for nitrification and denitrification in soils: Radiation and Environmental Biophysics, v. 13, p. 43–48.

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rittel, H.W.J., and Webber, M.M., 1973, Dilemmas in a General Theory of Planning: Policy Sciences, v. 4, p. 155–169.

2. MOVEMENT OF NITRATE FROM SEPTIC SYSTEMS ABOVE THE WATER TABLE

2.1 Introduction

Nitrate in public drinking waters is regulated to not exceed 10 mg/L in the USA under the 1974 Safe Drinking Water Act and in groundwater in Oregon under OAR 340-071. Nitrate is regulated because it has the potential to cause methemoglobinemia in infants (Comly, 1945; Walton, 1951) and can cause algal blooms in surface waters. It poses little health risk to children, adults, and seniors (Harper et al., 2017). Nitrate is ubiquitous in the environment and many natural waters have nitrate concentrations <3 mg/L (Madison and Brunett, 1984; Schlesinger and Bernhardt, 2013). Nitrates are also used in foods, pharmaceuticals, and fertilizers (Bedient et al., 1997; L'Hirondel and L'Hirondel, 2001).

People can be exposed to nitrate when water from septic systems reaches groundwater that serves as a source of drinking water (Fig. 1). Nitrate is derived from organic matter in septic effluent and is decomposed by microorganisms in soils. Soil microorganisms can also remove nitrate by decomposing it to form nitrogen gas. Under soil conditions beneath septic systems, the removal of nitrate is slower than nitrate formation, so nitrate can accumulate in soils (Grady et al., 2011; Madigan et al., 2015).

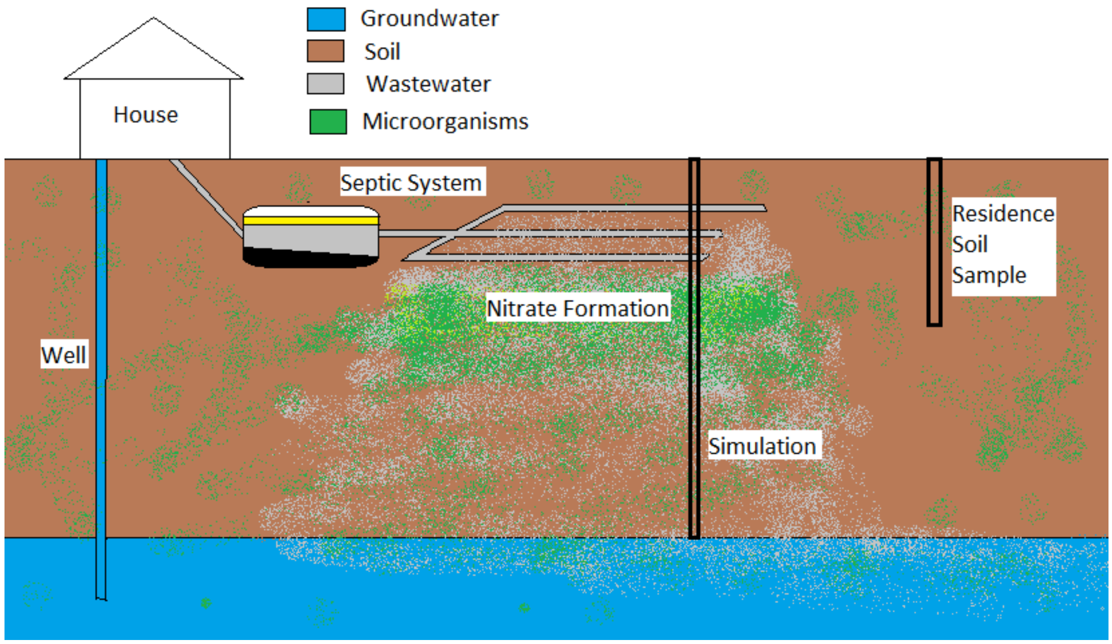


Fig. 1. Septic System Hydrology

It is well known that nitrate from septic systems can contaminate groundwater (Kendall and McDonnell, 1998). However, the transport of nitrate through the soils between the septic system and water table is less well understood because nitrate transport is affected by local soil conditions (Rolston et al., 1996; Rainwater and Jackson, 2004; Weaver, 2014).

This chapter investigates how much nitrate from septic systems reaches the water table in La Pine. The chapter also determines which analyses and methods are most effective for interpreting nitrate data and could be used for future projects.

The work in this chapter is based on questions posed by stakeholders in La Pine regarding nitrate contamination from septic systems.

2.2 Methods

Soil samples were taken from a residence in La Pine which had a septic system (Fig. 1) and from three areas with no septic systems. The soils were tested for nitrate, ammonia, total nitrogen, pH, moisture, electrical conductivity, organic matter, texture, infiltration, pH using test strips, and nitrate/nitrite using test strips.

Due to equipment limitations and permitting, soil samples could not be collected to the full depth of the water table or directly beneath a septic system. To estimate soil nitrate at deeper depths beneath a septic system, simulations were created using the HYDRUS 1D model (Fig. 1).

The simulation inputs were from the soil analysis and previous studies from the La Pine area (Rich, 2005; Morgan et al., 2007; Baird, 2016). Because the rate of nitrate removal from soils in previous studies was controversial, it was determined by simulating data from a study in Laramie, WY (Wenck Associates, 2019). The study in Laramie was used because there were a small number of studies on nitrate transport below septic systems (Appendix A) and soil textures were similar to La Pine.

2.3 Results and Discussion

Soil sampling established that soil nitrate concentrations were highest at the residence with a septic system, while there was little nitrate in soils where there were no septic systems (Fig. 2). It is likely that the high nitrate concentrations at the residence are from other nitrate sources besides septic systems, because the soil samples at the residence were taken 30 feet (ft) away from the nearest septic systems (Fig. 1). This trend in soil nitrate in La Pine did not match nitrate trends from other septic studies, where soils close to septic systems did not have elevated nitrate concentrations (>20 mg/kg) until a depth of 20-30 ft and nitrate concentrations slowly increased before decreasing with depth (Rolston et al., 1996; Izbicki et al., 2015; Wenck Associates, 2019).

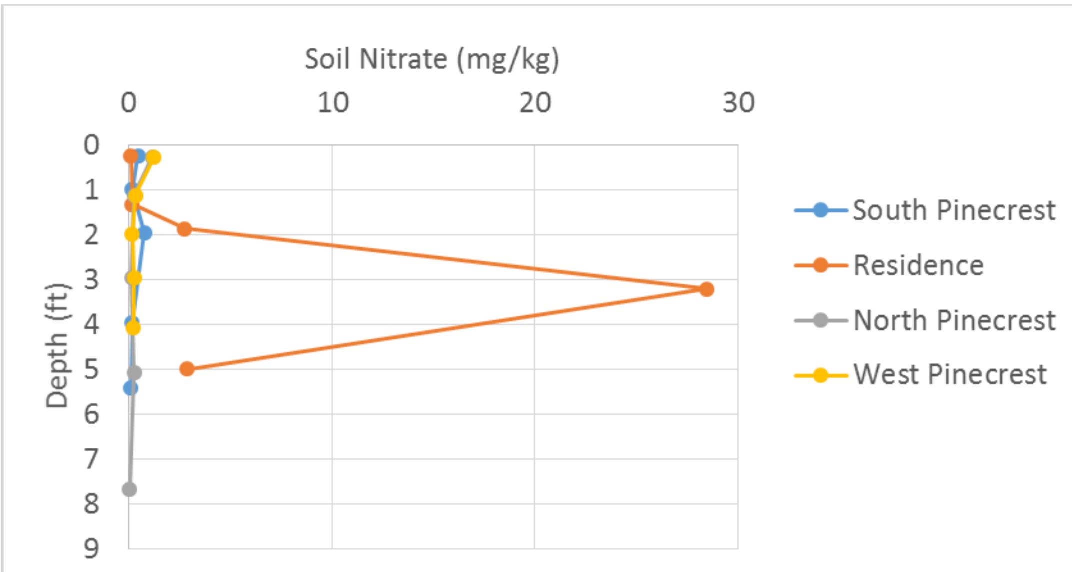


Fig. 2. Soil Nitrate from La Pine

Of the 11 soil tests, nitrate was the only analysis that showed a substantial difference between samples taken at the residence and at undisturbed sites (Fig. 3). Since there was little difference between sites, the non-nitrate soil test had little impact on the interpretation of nitrate results. The other soil tests may be more valuable depending on local conditions or for further analysis and modeling.

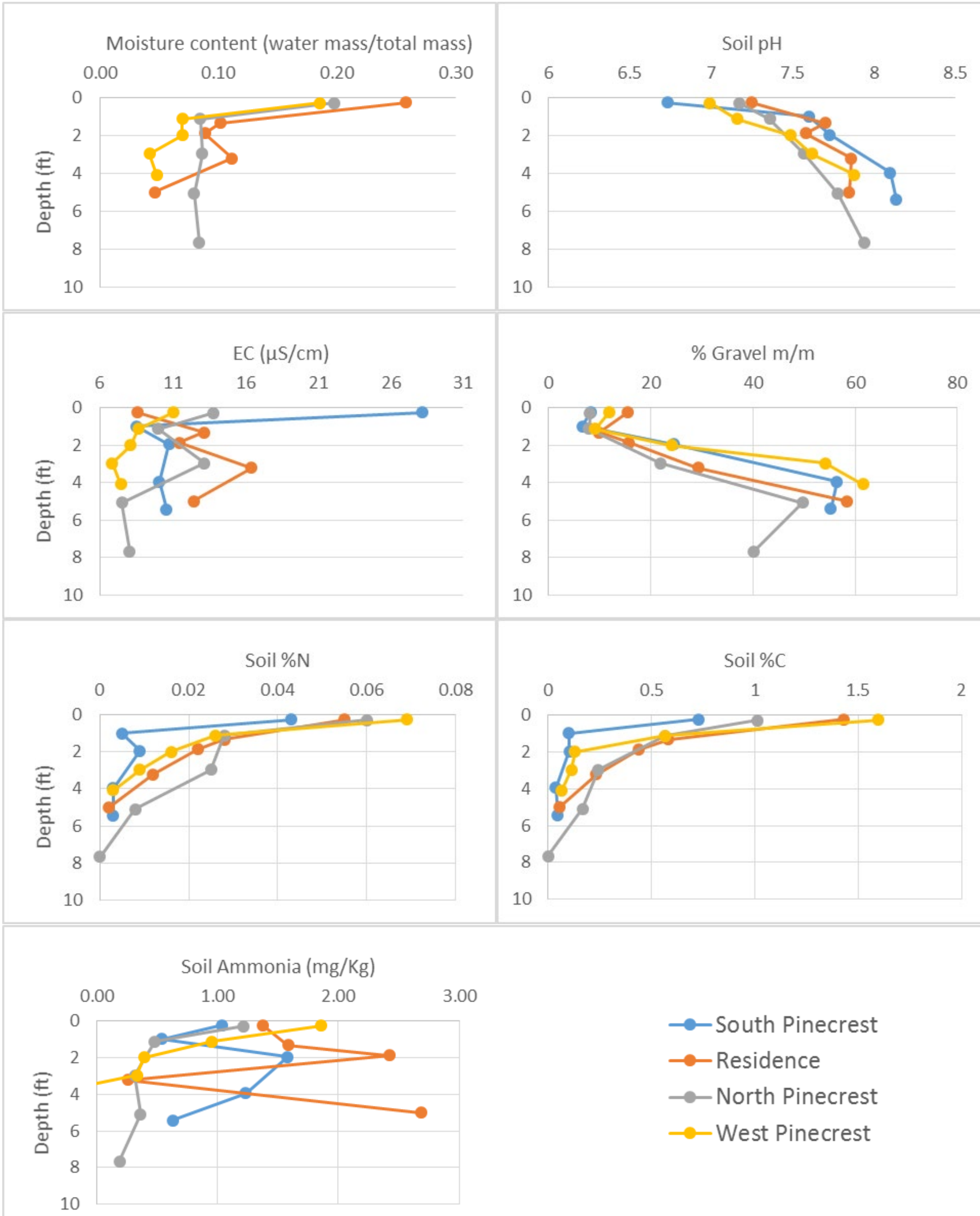


Fig. 3. Other Soil Tests from La Pine
Results for the soil tests not shown are in Appendix A

Simulations were not based on nitrate soil nitrate from La Pine, because the source of nitrate was uncertain. The inputs for the simulation in La Pine were based on results from the non-nitrate soil tests and previous studies of the area (Rich, 2005; Morgan et al., 2007; Baird, 2016). Nitrate removal from soils in the La Pine simulation was calculated by creating another simulation based on a septic system nitrate study in Laramie, WY (Fig. 4) (Wenck Associates, 2019).

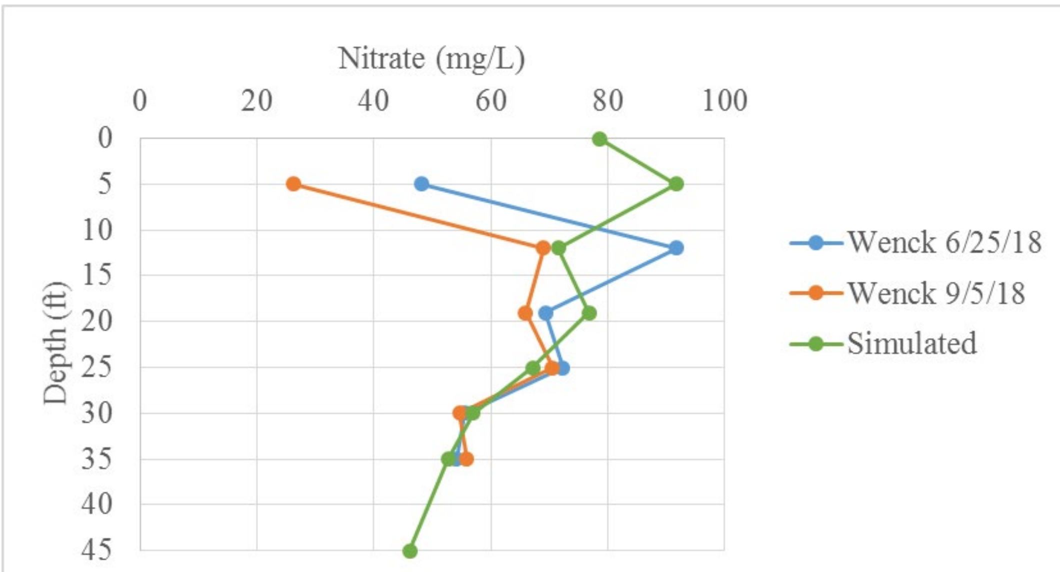


Fig. 4. Simulated and Observed Soil Nitrate in Laramie
Adapted from Wenck Associates (2019)

For the La Pine simulation (Fig. 5), two different soil conditions were simulated because soil tests were not taken below a depth of 8 ft, meaning that soil conditions were uncertain. Both simulations have the same soil conditions from a depth of 0-8 ft, based on soil sampling (Fig. 3), with soil textures ranging from sandy loam near the surface to extremely gravelly sand at a depth of 8 ft (detailed soil data is in Appendix A). One simulation assumes that the soil at the deepest soil tested (extremely gravelly sand) continued to the water table (La Pine Soil Test Simulation).

The other simulation is based on well logs that described soils below 8 ft as clay pumice (Prodan, 1989; La Pine Well Log Simulation).

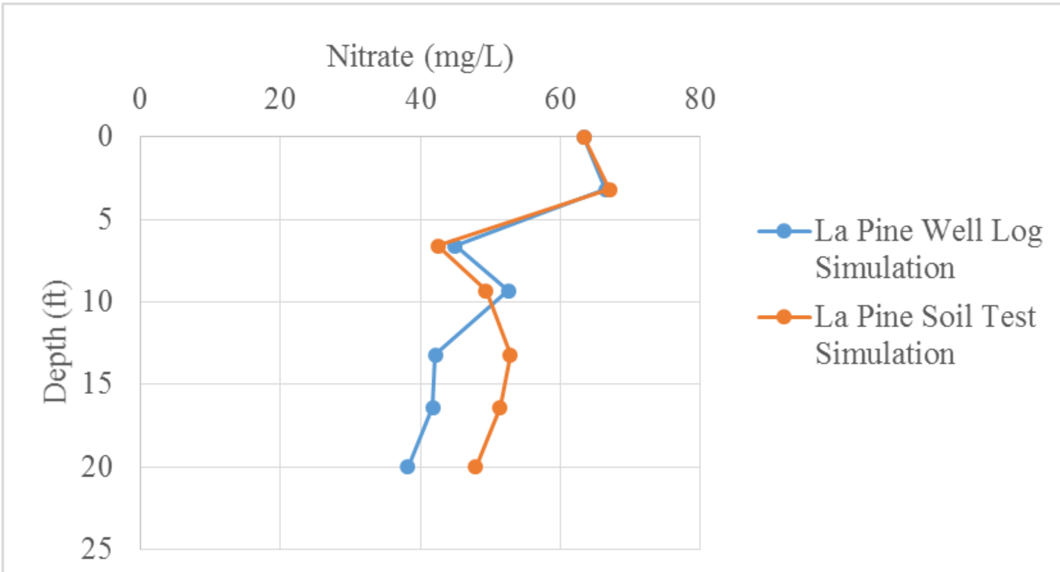


Fig. 5. La Pine HYDRUS Simulations of Water Nitrate

In the La Pine simulation based on collected soil samples, there was a nitrate removal of 24%. In the La Pine simulation based on well logs, there was a nitrate removal of 40%. The difference is attributed to simulated nitrate moving more slowly through the clay pumice, giving more time for nitrate removal. The simulations for this chapter corroborate previous studies of the La Pine area, which used 25% nitrate removal (Morgan et al., 2007).

2.4 Conclusions

Based on soil samples and simulations of nitrate transportation in La Pine, OR, the conclusions are:

(1) There was more nitrate in soils at residences with septic systems than at undeveloped locations, though the source of nitrate is uncertain.
(2) There was potential for a 24-40% reduction in nitrate by the time wastewater from septic systems reached the water table in La Pine.

(3) Other types of sampling were less significant for interpreting nitrate transport processes but were used to create simulations.
(4) Some simulation inputs from Laramie could be used for La Pine, though many inputs changed at different locations.

Conclusions from this chapter only apply to nitrate transport from the septic system to the water table. More research is required to develop a complete septic-system-to-well model that includes nitrate transport through groundwater below the water table. The nitrate concentrations in soils beneath septic systems are greater than nitrate concentrations which would be found in nearby wells (Hinkle et al., 2008). Nitrate in water from a septic system is diluted by groundwater, and the microorganisms in groundwater can also remove nitrate (Fig. 1; Wilson et al., 1990). In many areas, wells with high nitrate concentration can occur near wells with low nitrate concentrations (City of Laramie, 2010; Oregon Health Authority, 2019).

More information on this chapter can be found in Appendix A.

2.5 References

Baird, B.D., 2016, City of La Pine, Oregon: Water System Study Update: City of La Pine, Anderson Perry & Associates Job No. 33-05.

Bedient, P., Rifai, H.S., and Newell, C., 1997, Ground Water Contamination: Transport and Remediation: Upper Saddle River, NJ, Prentice Hall PTR, 603 p.

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area:

Comly, H., 1945, Cyanosis in Infants Caused by Nitrates in Well Water: Journal of the American Medical Association, v. 129, p. 112–116.

Grady, C.L.P., Daigger, G.T., Love, N.G., and Filipe, C.D.M., 2011, Biological Wastewater Treatment: CRC Press, 1022 p.

Harper, C. et al., 2017, Toxicological Profile for Nitrate and Nitrite: U.S. Department of Health and Human Services: Public Health Service: Agency for Toxic Substances and Disease Registry, p. 324.

Hinkle, S., Bohlke, J., and Fisher, L., 2008, Mass balance and isotope effects during nitrogen transport through septic tank systems with packed-bed (sand) filters: Science of The Total Environment, v. 407, p. 324–332, doi:10.1016/j.scitotenv.2008.08.036.

Izbicki, J.A., Flint, A.L., O'Leary, D.R., Nishikawa, T., Martin, P., Johnson, R.D., and Clark, D.A., 2015, Storage and mobilization of natural and septic nitrate in thick unsaturated zones, California: Journal of Hydrology, v. 524, p. 147–165, doi:10.1016/j.jhydrol.2015.02.005.

Kendall, C., and McDonnell, J.J., 1998, Isotope Tracers in Catchment Hydrology: Elsevier, 839 p., https://www.rcamnl.wr.usgs.gov/isoig/isopubs/itchch16.html.

L'Hirondel, J., and L'Hirondel, J.L., 2001, The case against nitrate: a critical examination, *in* L'Hirondel, J. and L'Hirondel, J.L. eds., Nitrate and man: toxic, harmless or beneficial?, Wallingford, CABI, p. 35–68, doi:10.1079/9780851995663.0035.

Madigan, M., Martinko, J., Bender, K., Buckley, D., and Stahl, D., 2015, Brock Biology of Microorganisms: Pearson Education Limited, 1030 p.

Madison, R.J., and Brunett, J.O., 1984, Overview of occurrence of nitrate in groundwater of the United States, *in* National Water Summary 1984 - Hydrologic Events, Selected Water-Quality Trends and Ground-water Resources., US Geological Survey, Water-Supply Paper 2275, p. 93–105.

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Oregon Health Authority, 2019, Oregon Public Health: Drinking Water Data Online:, https://yourwater.oregon.gov/ (accessed June 2019).

Prodan, M., 1989, State of Oregon Water Well Report: DESC 7009:

Rainwater, K., and Jackson, A., 2004, Evaluation of Drainfield Absorption and Evapotranspiration Capacity: Texas On-Site Wastewater Treatment Research Council, 73 p., https://www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/PhaseII-Report.pdf (accessed January 2019).

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rolston, D.E., Fogg, G.E., Decker, D.L., Louie, D.T., and Grismer, M.E., 1996, Nitrogen isotope ratios identify nitrate contamination sources: California Agriculture, v. 50, p. 32–36, doi:10.3733/ca.v050n02p32.

Schlesinger, W.H., and Bernhardt, E.S., 2013, Biogeochemistry: An Analysis of Global Change: Elsevier, Academic Press, 672 p.

Walton, G., 1951, Survey of Literature Relating to Infant Methemoglobinemia Due to Nitrate-Contaminated Water: American Journal of Public Health and the Nation's Health, v. 41, p. 986–996, doi:10.2105/AJPH.41.8_Pt_1.986.

Weaver, C., 2014, Effectiveness of Suction Lysimeters in Determining Contaminant Transport Within Leaching Bed Systems: University of Guelph.

Wenck Associates, 2019, Albany County Septic System Impact Analysis: Wenck Associates, Albany County, Wyoming Department of Environmental Quality, 269 p.

Wilson, G.B., Andrews, J.N., and Bath, A.H., 1990, Dissolved gas evidence for denitrification in the Lincolnshire Limestone groundwaters, eastern England: Journal of Hydrology, v. 113, p. 51–60, doi:10.1016/0022-1694(90)90166-U.

3. THE EFFECT OF HISTORY AND SETTING ON NOWTS CONFLICTS (LA PINE AND LARAMIE)

3.1 Introduction

Rural residents in La Pine, OR and Laramie, WY dispose of wastewater by using septic systems or other types of onsite wastewater treatment systems (OWTS). OWTS (septic systems are a type of OWTS) treat wastewater and then release it underground, where wastewater is further treated as it infiltrates through the soil.

Wastewater from septic systems that is not fully treated has the potential to contaminate groundwater. Groundwater is often the only source of potable water for rural residents on private wells. One of the groundwater contaminants of concern is nitrate, which has been attributed to causing methemoglobinemia in infants (Comly, 1945).

There have been decades of political conflict in La Pine, OR and Laramie, WY over the issue of groundwater that contains nitrate from onsite wastewater treatment systems (NOWTS, pronounced like "knots"). The conflicts over NOWTS are complex, and part of the conflict pertains to whether NOWTS is an issue or not, since >95% of wells are below limits (City of Laramie, 2010; Oregon Health Authority, 2019).

The purpose of this chapter is to determine how the history and setting of the political conflict over NOWTS in La Pine and Laramie affected stakeholders involved in the conflicts. In this chapter, 'stakeholders' includes anyone who had an interest or concern in the NOWTS conflicts in La Pine and Laramie. Stakeholders may be residents, governments, experts, or other groups.

3.2 Methods

Stakeholder information was collected in La Pine through meetings and surveys, which were conducted concurrently with an environmental science investigation in La Pine (Chapter two). Stakeholder information in Laramie was collected through interviews and information was collected to create an updated conflict assessment for Laramie (Jarvis, 2014). Information from La Pine and Laramie was supplemented by local newspaper articles, journal articles, US Geological Survey reports, agency reports, consultant reports, city/county/non-governmental organization documents, laws, websites, and academic graduate theses.

The information on the conflicts was organized by using the Circle of Conflict and situation maps. The Circle of Conflict is a wheel diagram used to categorize the parts of a conflict (Moore, 1986). Situation maps are a form of information mapping used to map out parts or groups involved in a conflict (elements) and their connections (Daniels and Walker, 2012).

The results section is used to frame the conflicts in La Pine and Laramie. The discussion section compares the conflicts in La Pine and Laramie, focusing on the effects of the setting and history of the conflict on stakeholders.

3.3 Results

3.3.1 Setting and History of La Pine

The City of La Pine is located in Central Oregon, 28 miles south of Bend, OR. There were 1,653 residents in the City of La Pine in the 2010 US Census, with an estimated 18,000 residents and 7,000 septic systems in the outlying areas (Morgan et al., 2007). NOWTS has been an issue since 1979, when nitrate was found over 10 mg/L in well water, which is the level at which the Oregon Department of Environmental Quality (ODEQ) is required to take action under state law (OAR 340-40).

More recent conflict started in the late 1990s, when Deschutes County put in place a number of studies, programs, sewer construction projects, and stricter land use regulations to address NOWTS. The most contentious regulations were county ordinances in 2008 (Ordinance 2008-021) requiring residents to construct OWTS that treated for nitrate. These regulatory actions were rescinded in a special election the following year by rural residents who opposed the regulations (Nigg and Baggett, 2013).

Table 1. Views of the Conflict in La Pine

	Regulators	Rural Residents
Affiliated Groups	Oregon Department of Environmental Quality (ODEQ), Deschutes County Government, US Geological Survey	Residents of the La Pine Area, Deschutes County Citizen's Action Group, retired experts
Connection to groundwater	Under law, the state and county governments are responsible for protecting groundwater quality and public health.	Groundwater is the sole source of water for residents of the area.
Perception of the 'problem'	Wells have been found with nitrate over 10 mg/L in the La Pine Area, which by law poses a health risk to the residents of La Pine. The source of nitrate is septic systems.	The issue is not as urgent since only a small number of wells have nitrate over 10 mg/L, and numbers are stable. Nitrate poses little risk to the community since it has had no impact on health or the environment.
Concerns	Protect health for the community. Infrastructure is unable to support population growth (54% 1990 - 2000). Because of the shallow water table and wells, La Pine is more at risk.	Government actions did not match the severity of the problem. Regulations were unaffordable to residents, costing $2,250-18,000. Government information did not match local knowledge. Residents wanted less government intervention.

After the ordinances in 2008, conflict diminished as ODEQ created a committee formed by residents to try and find compromises and regulations that were less controversial. Some of the compromise regulations were rescinded due to backlash by stakeholders and NGOs (Ryan et al., 2016).

In communication with government and stakeholders in La Pine, both groups were fatigued by the conflict. At the time of this dissertation, the government had stepped back from the conflict due to a lack of resources. Because there was less government action for stakeholders to oppose, many stakeholders also stepped back from the conflict.

In 2017, approval for septic systems and OWTS was on a case-by-case basis by Deschutes County and ODEQ.

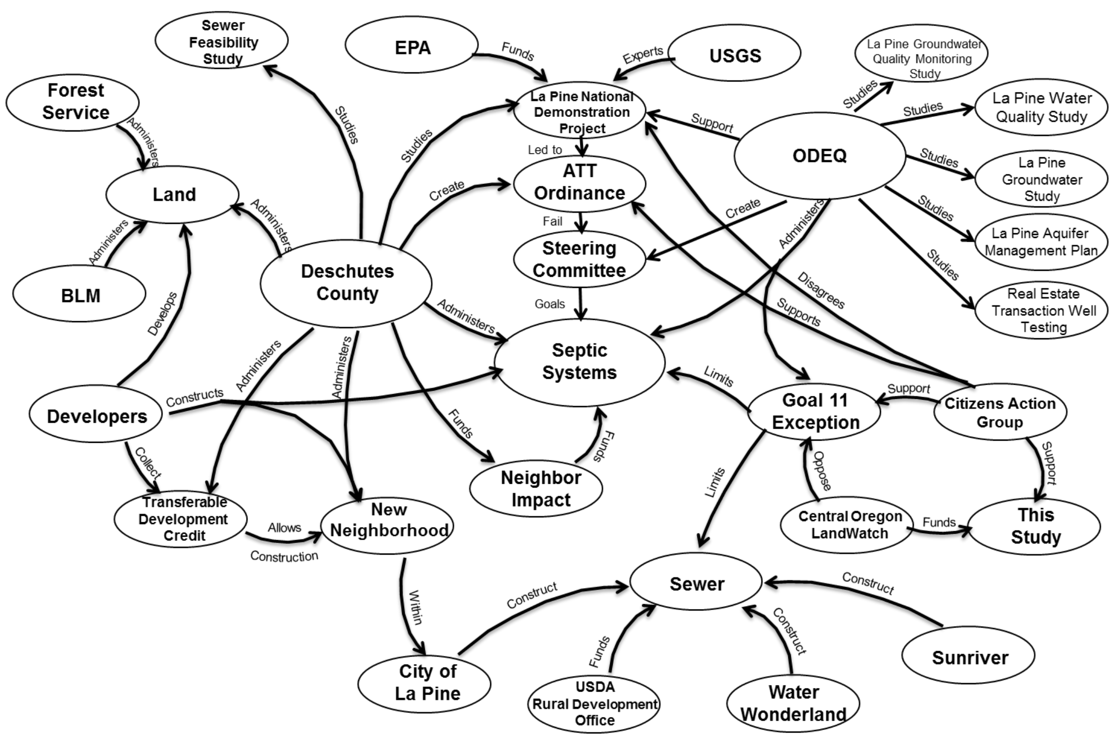


Fig. 6. La Pine Situation Map

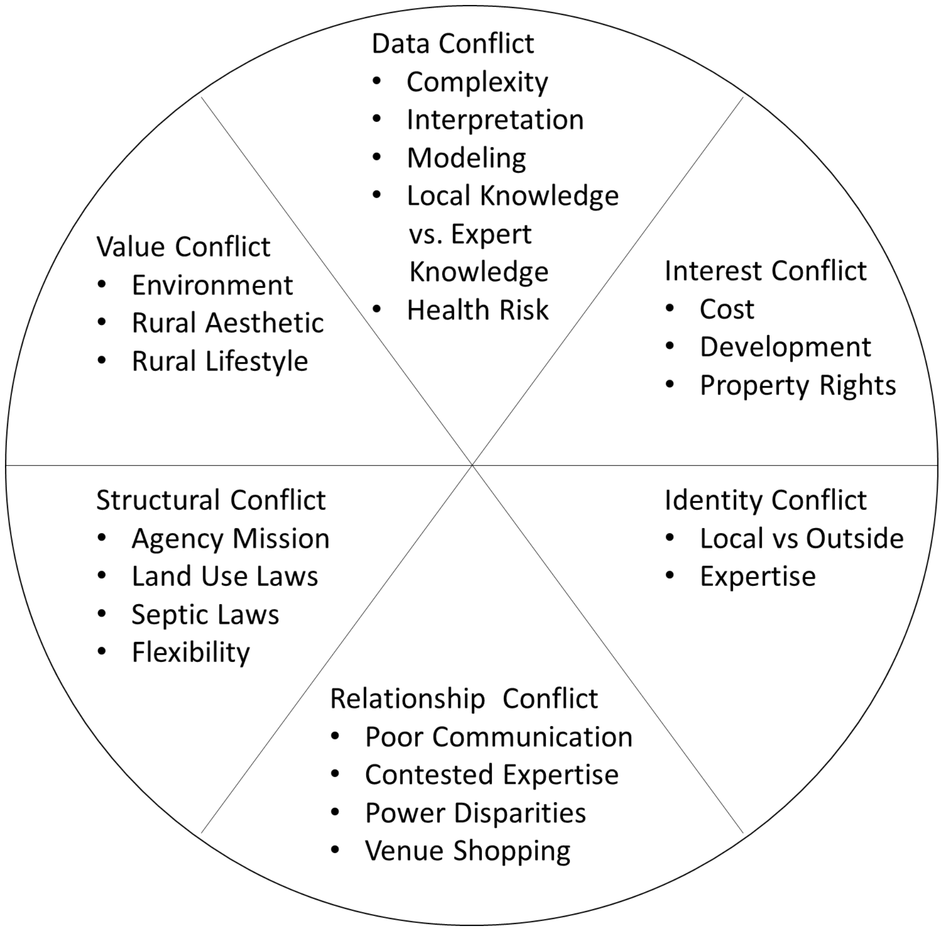


Fig. 7. La Pine Circle of Conflict

3.3.2 Setting and History of Laramie

The City of Laramie is in Albany County, which is located in southeastern Wyoming on High Plains, on the west side of the Laramie Range. According to the 2010 US Census, there were 30,816 people in Laramie, including 13,657 students at the University of Wyoming (UW). Laramie also has a community of water experts who worked for UW, state agencies, and multiple local consulting firms.

The Casper Aquifer provides 60% of the water for the City of Laramie, as well as all of the water for private well owners within the vicinity of Laramie but outside and to the east of city limits. As of 2008, the well owners had approximately 400 septic systems (Wittman Hydro Planning Associates (WHPA), 2008).

The City of Laramie and Albany County started taking action to protect the Casper Aquifer during the 1990s to comply with a 1986 amendment to the Safe Drinking Water Act, which included protection for wells and groundwater. From the start of aquifer protection to the time of this dissertation, many of the regulations created to protect the Casper Aquifer were less controversial and had support from the majority of urban and rural residents. From the 1990s to 2008, conflict occurred periodically when actions (government regulation enforcement or stakeholder lobbying) were taken to impede business and residential developments, many of which were outside of city limits (Jarvis, 2014).

The conflict escalated during the 2008 update to the Casper Aquifer Protection Plan (CAPP), created by an out-of-state consulting firm. The City of Laramie was motivated to update the CAPP due to a conflict over the expansion of the UW golf course, which included a residential subdivision. According to those interviewed, the more controversial parts of the 2008 CAPP were the recommendations to connect private well owners to sewer systems and to expand the western boundary of the CAPP to align with political boundaries (WHPA, 2008). Because earlier versions of the CAPP were created by stakeholders and experts from the local community, the 2008 CAPP had less credibility to private well owners (Starkey, 2008). Those participating in the conflict split along the urban-rural divide based on different interpretations of what the CAPP represented, and different values associated with aquifer protection (Table 2; Chapter four). As a result of the conflict, the Wyoming Board of Professional Geologists determined that the consultant was practicing geology without a license, and the City of Laramie and Albany County created separate CAPPs (Albany County Planner, 2011).

Table 2. Views of Urban and Rural Groups.

	Urban	Rural
Affiliated Groups	Laramie City Council, Albany County Clean Water Advocates, experts who are city residents.	Albany County Commissioners, CAP Network, private well owners, experts who are private well owners.
Connection to the Casper Aquifer	60% of the water for the City of Laramie comes from the Casper Aquifer.	The Casper Aquifer is the sole source of water for well owners.
Perception of the 'problem'	The Casper Aquifer is our water source and should be protected. Septic systems are contaminating the Casper Aquifer and are a potential threat to the water supplies of private well owners and the city.	The Casper Aquifer is our only water source and should be protected. A small number of wells have elevated nitrate, which may be from other sources (nitrogen fixation, historic livestock, poorly maintained wells and septic systems). The contribution of NOWTS is not definitively known.
Values and interests	Want to take precautionary steps to stop contamination before it can occur. Favor stricter enforcement of land use regulations to protect open space, the viewshed, and the aquifer.	Wants regulatory response to be balanced by the impact on costs, property rights, and other burdens placed on private well owners. There needs to be more evidence of a defined problem to justify regulations that will have a greater impact.

* More detailed information on the views of stakeholders are in Appendix B.

According to the stakeholders interviewed, after the conflict over the 2008 CAPP, the conflict over the Casper Aquifer diminished, albeit with occasional conflicts over developments, land use regulations, and groundwater studies (Chapter four).

Other changes to the structure of the conflict were that the City of Laramie could no longer regulate areas outside of Laramie, due to changes in state laws (HB 85 in 2013, HB 14 in 2018). The stakeholders interviewed on all sides of the conflict felt some fatigue with the conflict, but it took only a few dedicated people to create political change or to start the processes which would escalate the conflict.

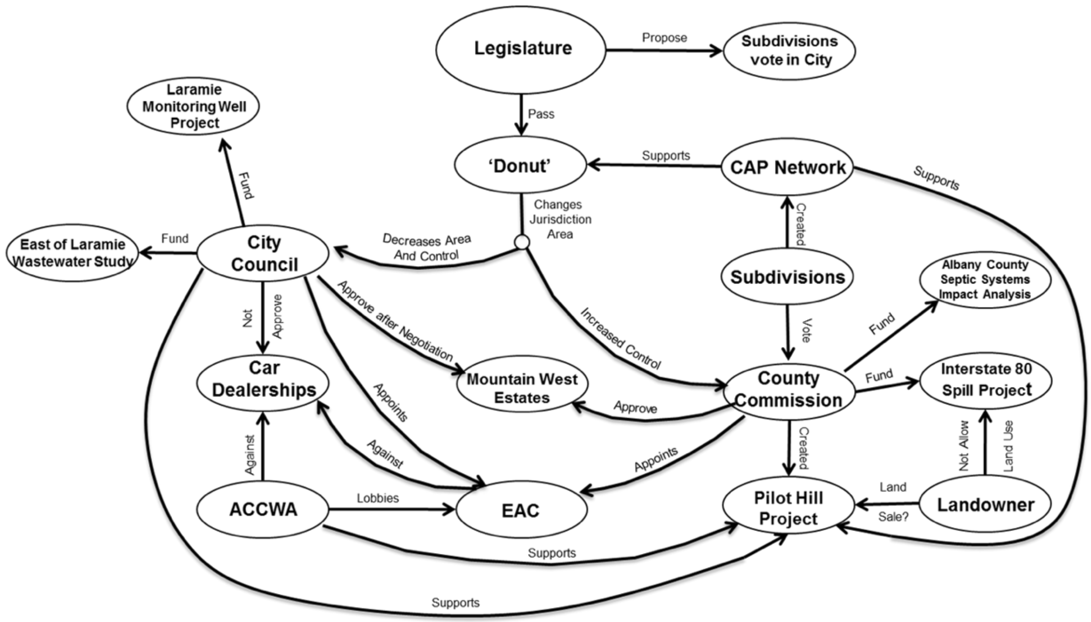


Fig. 8. Groups, Studies, and Regulations Involved in Conflicts in Laramie 2013-2018

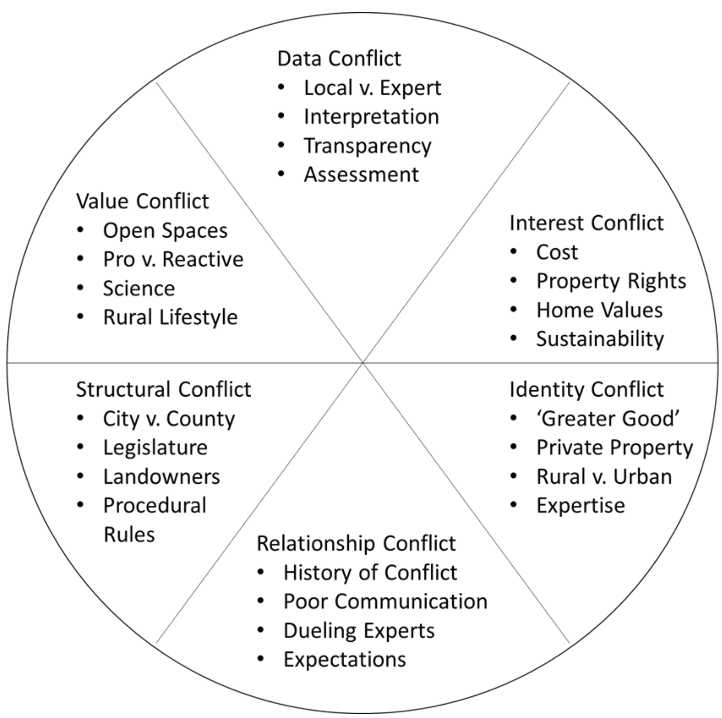


Fig. 9. Facets of Conflicts in Laramie 2013-2018

Table 3. Changes in Situation Maps and Circles of Conflict 1990-2018

Topic		1990s	2013	2018
Situation Maps		Small Scale conflict with a small number of groups.	Height of conflict, where many groups are involved. Opposing sides, city and county.	Decrease in groups as conflict de-escalates. Many groups are less active in the conflict.
Circles of Conflict	Values	• Science • Risk • Precautionary Principle	• Open Space • Drinking Water • Science • Rural Lifestyle	• Open Space • Proactive vs. Reactive • Science • Rural Lifestyle
	Data	• Interpretation • Assessment	• Interpretation • Assessment • Lack of Data • Missing Data • Procedures	• Interpretation • Assessment • Local v. Expert • Transparency
	Interest	• Business Opposition • Competition • Procedure	• Property Rights • Home Values • Future Gens.	• Property Rights • Home Values • Sustainability • Cost
	Structural	• City v. County • Rural v. Urban • Landowners	• City v. County • Legislature • Landowners • University	• City v. County • Legislature • Landowners • Procedural Rules
	Relationship	• Dueling Experts	• Dueling Experts • Poor Communication • Emotions	• Poor Communication • Dueling Experts • History of Conflict • Expectations
	Identity	• Reputation • Recognition	• 'Greater Good' • Private Property • Urban vs. Rural	• 'Greater Good' • Private Property • Rural v. Urban • Expertise

Explanation: The situation maps and circles of conflict are condensed in this table. The 2018 column under the situation map row is a description of Fig. 8. The 2018 column under the Circles of Conflict row is the same information as in Fig. 9 but in table form instead of a wheel diagram. The Circles of Conflict are displayed in table form instead of in wheel diagrams and all of the information is retained. The full situation maps and Circles of Conflict for 1990 and 2013 are from Jarvis (2014).

3.4 Discussion

The discussion builds upon the information provided in the results section, comparing how stakeholders in La Pine and Laramie viewed the conflicts and identifying aspects of the setting and history of conflict that may have motivated stakeholder views. The information in this section is based on views expressed by stakeholders in La Pine and Laramie through surveys, interviews, and other communications.

In La Pine and Laramie, the sides of the conflict tended to align with the urban-rural divide. Three aspects of the urban-rural divide were noted in communications with stakeholders—distance, power disparity, and values. There was more physical and social distance between urban and rural groups in La Pine than in Laramie. In Laramie, the majority of rural residents lived within 1 mile of Laramie, and in interviews, stakeholders spoke about the effects the conflict had on friendships. In La Pine, urban groups were in Bend, 28 miles away, and stakeholders did not mention the effect of the conflict on personal relationships. In the conflicts in both La Pine and Laramie, there was a power disparity in that urban governments had the ability to regulate rural areas, which was met by resistance from rural residents who were not/less represented in urban governments. The power disparities shifted over time, giving rural residents more influence in decision-making.

The values expressed by urban and rural residents were similar between La Pine and Laramie. Urban and rural residents both wanted to protect groundwater using science but differed on how this was accomplished. Urban groups wanted stronger land use regulations to stop any potential groundwater contamination. Rural groups wanted regulations to take into account the impact of regulations on personal costs and property rights.

While the values and arguments used in La Pine and Laramie were similar, the focus of the arguments was different. In interviews in Laramie, stakeholders mentioned hydrogeology and the technical aspects of septic systems more than stakeholders in La Pine did. In La Pine, stakeholders mentioned the health risks more than stakeholders in Laramie did. The focus in Laramie could have been due to the consolidated sediments stratigraphy, which is well defined (Fig. 10). In La Pine, sediments are unconsolidated and complexly layered, and this uncertain geology made it more difficult to argue about specific aspects of the geology.

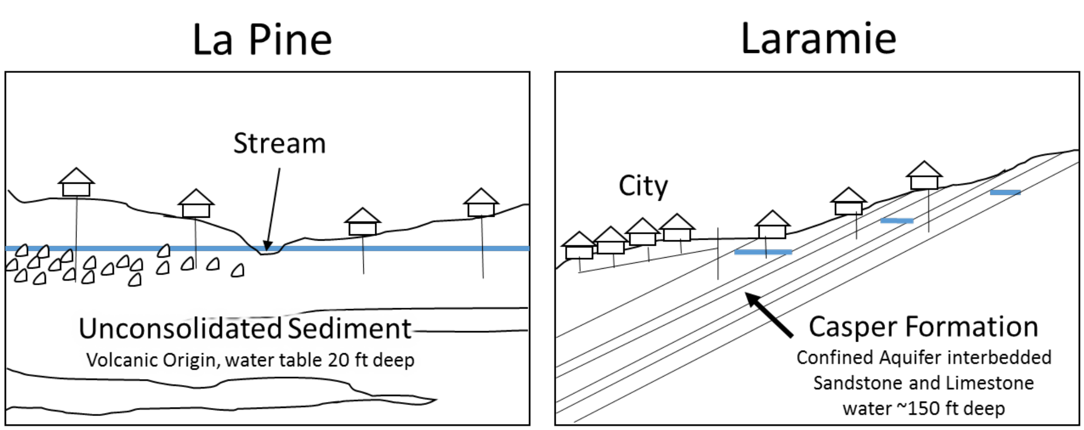


Fig. 10. Schematic Diagram of the Hydrology of La Pine and Laramie

The history of the conflict affected stakeholders in three ways: (1) stakeholder knowledge, (2) views of other stakeholders, and (3) fatigue.

As stakeholders (including residents, regulators, and experts) participated in conflicts, they became more knowledgeable of the science and politics behind those conflicts. Stakeholders learned about NOWTS through many different sources (documents, conversations, websites, personal experience, newsletters, etc.), which gave stakeholders different understandings of it. Stakeholders had different interpretations because although the scientific theory behind NOWTS is well understood, NOWTS can vary greatly depending on local conditions (McLaren, 1976; Ahola, 2017). The different understandings of NOWTS made it so there was less agreement on issues involved in the conflict.

As stakeholders (including residents, regulators, and experts) participated in conflicts, they also formed opinions of other stakeholders based on their past interactions with those stakeholders. These opinions in turn colored future interactions stakeholders had with each other in ways that often reinforced their existing opinions. For example, when stakeholders had a negative opinion of another stakeholder, they would have less trust in that stakeholder and would be more likely to negatively interpret them, which created conflicts that further reinforced the negative opinion. The inverse occurred for positive opinions.

As stakeholders participated in the decades of NOWTS conflicts they became fatigued by the conflict. The amount of fatigue stakeholders experienced varied by individual. There were many symptoms of fatigue that included:

- A general sense of frustration over the conflict and groups involved
- A lack of time, motivation, or resources to continue the conflict
- Being more selective in choosing opportunities to address conflict
- Wanting to find successors to continue the conflict

Additionally, some stakeholders were satisfied enough with the situation to not participate in the conflict.

This dissertation proposes two frameworks for thinking about stakeholder fatigue as either a feedback loop or an interest curve (Fig. 11). The feedback loop framework was more appropriate in La Pine, where more controversial regulations were consistently blocked by stakeholders. Because there were few lasting regulatory changes and limited resources, regulators stepped back from creating regulations. Other stakeholders stepped back because there were fewer controversial regulations to fight against.

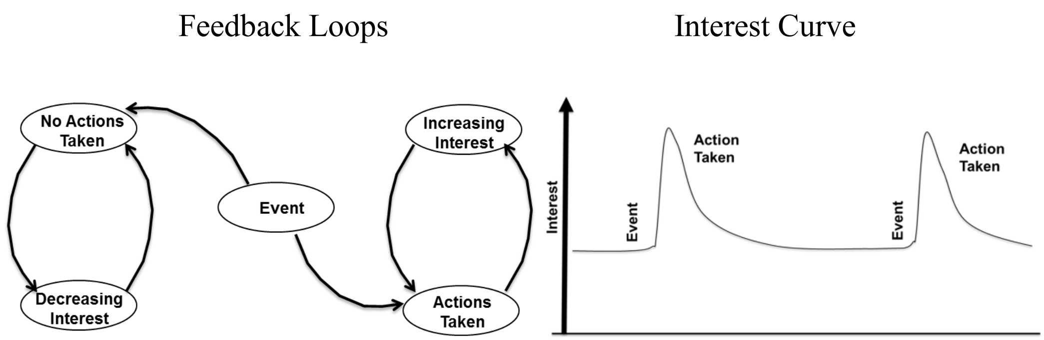


Fig. 11. Fatigue Feedback Loops and Interest Curves

The interest curve framework was more apt in Laramie. Stakeholders had a consistent baseline interest in NOWTS issues, but controversial events (development, regulation, plan, or study) increased stakeholder interest. After the conflict was resolved or as the conflict dragged on, stakeholder interest would decrease back to the baseline.

The role of experts as stakeholders in NOWTS science in La Pine and Laramie is highly complex and is explained in more detail in Chapters four and five.

3.5 Conclusions

This chapter provided conflict assessments for the conflicts over groundwater protection and NOWTS in La Pine and Laramie. As part of the assessment process, the following conclusions were created by comparing the conflict in La Pine and Laramie.

- Stakeholders were split based on the urban-rural divide in La Pine and Laramie. Though there were differences in the structure of the divide, rural groups in both areas shared similar values.
- Arguments used by stakeholders in Laramie focused more on geology, while in La Pine they focused more on the impacts on human health. This could be because the geological stratigraphy in Laramie is better defined than in La Pine.
- Stakeholders became more knowledgeable as they participated in conflicts. Knowledgeable stakeholders were more politically savvy. Knowledge was not standardized, so stakeholders had more conflicting views of NOWTS.
- Stakeholders and experts formed opinions of other stakeholders based on their history of interactions. These opinions set the tone for future interactions that tended to reinforce existing opinions.
- Stakeholders in La Pine and Laramie felt some form of fatigue when addressing the decades-long NOWTS conflict. Signs of fatigue ranged from being less active in the conflict to frustration over stakeholders or issues.

3.5.1 Policy Recommendations

This chapter makes two policy recommendations for the conflicts in La Pine and Laramie. The first recommendation, based on the fatigue interest curve framework (Fig. 11), is to increase the scale of the conflict (Karkkainen; Ostrom, 1990; Heikkila and Gerlak, 2005; Wolf et al., 2010). The scale of the conflict can be increased by addressing larger scale issues. For example, in Laramie, NOWTS was part of the greater issue of aquifer protection. Another strategy is to build coalitions of multiple groups to further expand the scale of conflict. While groups in La Pine and Laramie have worked with other groups on local and national scales, these efforts could be further expanded.

The second recommendation is to have more joint projects (including joint fact-finding). This recommendation is based on the fatigue feedback loops (Fig. 11). Multiple groups could cooperate on smaller scale, less contentious projects. The small scale projects would be used to build trust between groups and as motivation for larger projects (O'Brien, 2012). There are multiple ongoing collaborative projects in Laramie that could be leveraged to build trust between stakeholders (Pilot Hill Project, 2019; Achs and Bendtsen, 2019).

More information on this chapter can be found in Appendix B.

3.6 References

Achs, J., and Bendtsen, D., 2019, Officials hope aquifer study helps create better policies: Laramie Boomerang 29 June, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/officials-hope-aquifer-study-helps-create-better-policies/article_3e91486b-650c-5762-a978-cb040c5f7ead.html (accessed November 2019).

Ahola, S., 2017, Why (not) disagree? Human values and the readiness to question experts' views: Public Understanding of Science, v. 26, p. 339–354, doi:10.1177/0963662516637818.

Albany County Planner, 2011, Casper Aquifer Protection Plan: Albany County, Wyoming, 132 p.

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area:

Comly, H., 1945, Cyanosis in Infants Caused by Nitrates in Well Water: Journal of the American Medical Association, v. 129, p. 112–116.

Daniels, S.E., and Walker, G.B., 2012, Lessons from the Trenches: Twenty Years of Using Systems Thinking in Natural Resource Conflict Situations: Systems Thinking and Natural Resource Conflict: Systems Research and Behavioral Science, v. 29, p. 104–115, doi:10.1002/sres.2100.

Heikkila, T., and Gerlak, A.K., 2005, The Formation of Large-scale Collaborative Resource Management Institutions: Clarifying the Roles of Stakeholders, Science, and Institutions: Policy Studies Journal, v. 33, p. 583–612, doi:10.1111/j.1541-0072.2005.00134.x.

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

Karkkainen, B.C., Collaborative Ecosystem Governance: Scale, Complexity, and Dynamism:

McLaren, A.D., 1976, Rate constants for nitrification and denitrification in soils: Radiation and Environmental Biophysics, v. 13, p. 43–48.

Moore, C., 1986, The mediation process : practical strategies for resolving conflict: San Francisco, Jossey-Bass.

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Nigg, E., and Baggett, R., 2013, South Deschutes/North Klamath Groundwater Protection: Report and Recommendations: Oregon Department of Environmental Quality, 32 p.

O'Brien, M., 2012, Review of collaborative Governance: Factors Crucial to the internal workings of the collaborative process: New Zealand Ministry for the Environment Publication Number CR 135.

Oregon Health Authority, 2019, Oregon Public Health: Drinking Water Data Online:, https://yourwater.oregon.gov/ (accessed June 2019).

Ostrom, E., 1990, Governing the Commons: The Evolution of Institutions for Collective Action: Cambridge University Press.

Pilot Hill Project, 2019, The Pilot Hill Project: Pilot Hill Project, http://pilothill.org/ (accessed April 2019).

Ryan, Holstun, and Bassham, 2016, Before the Land Use Board of Appeals of the State of Oregon: Central Oregon Landwatch (petitioner), vs. Deschutes County (Respondent) and Oregon Department of Environmental Quality: v. LUBA No. 2016-020, p. 33.

Starkey, K., 2008, Give credit where credit is due: Laramie Boomerang 18 September.

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

Wolf, A.T. et al., 2010, Sharing Water, Sharing Benefits; Working Towards Effective Transboundary Water Resources Management: United Nations Education, Scientific and Cultural Organization, 284 p.

4. GOVERNMENT EXPERTS, CONSULTANTS, AND ACADEMICS

4.1 Introduction

In La Pine, OR and Laramie, WY, the majority of rural residents treat their wastewater using conventional septic systems. A minority of rural residents use other types of onsite wastewater treatment systems (OWTS) (septic systems are a type of OWTS). Wastewater is treated within septic systems and as wastewater infiltrates through the soil to groundwater. If the water is not completely treated in soils, it can contaminate groundwater used for drinking water (Chapter two).

In La Pine and Laramie, there have been decades of conflict over the amount of nitrate from OWTS that contaminates groundwater and the appropriate regulatory response to potential contamination from OWTS. Many different stakeholders (including experts) were involved in the conflicts (Chapter three). One component of the conflicts was how government experts, academics, and consultants (GAC experts) communicated with stakeholders. In this chapter, *GAC experts* specifically refers to government experts, consultants, and academics, while the term *expert* applies to all people or groups that have definitive knowledge of a topic.

GAC experts are involved and play multiple roles in political conflicts over environmental issues: the *pure scientist* who only looks at facts and has no political interactions, the *science arbiter* who answers specific stakeholder questions, the *issue advocate* who limits choices by advocating for a certain choice, or the *honest broker* who clarifies or expands the choices available (Pielke, 2007).

The roles experts play create communication issues between stakeholders and experts, such as the pure scientists' detachment from politics (Pielke, 2007). Other communication issues arise from the varied roles experts play in conflict:

- Experts can have multiple roles (including the role of stakeholder).
- Experts can change roles.
- Stakeholders can view experts as playing a different role than experts view themselves as playing (Pielke, 2007; Ahola, 2017).

Another communication issue that creates social distance between experts and stakeholders is the difficulties experts have in communicating the nuances of complex issues to people, including other experts in their own discipline (Ahola, 2017). Often stakeholders (including experts) have different knowledge bases and are trained to communicate differently (Lackey, 2004).

The purpose of this chapter is to add to the growing body of work on conflict and science communication, by showing how the conflicts in La Pine and Laramie were affected by the way GAC experts communicated with stakeholders. It is important to understand these communication issues in order to better manage environmental conflicts.

4.2 Methods

Case studies were created based on five controversial studies by GAC experts in La Pine and Laramie. For La Pine, the chapter focuses on The La Pine National Demonstration Project (LPNDP) and Fate and Transport of Nitrate from Septic Systems (Chapter two). For Laramie, the chapter focuses on the 2008 update to the Casper Aquifer Protection Plan (2008 CAPP), the 2009/2010 Monitoring of the

Casper Aquifer Protection Area (MCAPA), and the Albany County Septic System Impact Analysis (ACSSIA).

For each case study, a summary of the project is provided, followed by the stakeholder responses to the study. The stakeholder responses are based on surveys, interviews, and other communications. Where possible, information from the surveys and interviews was corroborated with local newspaper articles, journal articles, US Geological Survey reports, agency reports, consultant reports, city/county/non-governmental organization documents, laws, websites, and graduate theses.

Whenever the term interview is used in this chapter, it refers to people who were interviewed by the author.

4.3 Results

4.3.1 La Pine National Demonstration Project

The La Pine National Demonstration Project (LPNDP) was conducted by the US Geological Survey (USGS), Oregon Department of Environmental Quality (ODEQ), and Deschutes County. The LPNDP was motivated by concerns that NOWTS was a growing issue because there were ~7,000 homes on septic systems in the La Pine Area. The population of Deschutes County also grew by 54% between 1990 and 2000 (Watershed Professionals Network, 2002; Rich, 2005). The LPNDP was a large project that had many parts. Twelve types of OWTS were installed in homes that were then tested to determine how well the OWTS treated nitrate (to form nitrogen gas). Hydrologic and contaminant transport models were created and policy options were developed to address potential NOWTS issues (Rich, 2005; Morgan et al., 2007). The LPNDP was communicated to stakeholders through public meetings, reports, journal articles, pamphlets, and webpages (Rich, 2005; Ramsayer, 2006; Williams et al., 2007).

The Deschutes County government took multiple regulatory actions based on the LPNDP. The most controversial regulation was Ordinance 2008-012, which required residents to construct expensive nitrate-treating OWTS. Another controversial regulation was the expansion of the Oregon Land Use Goal 11 exception area, which would have allowed the construction of sewers and clustered wastewater treatment systems outside city limits. Both regulations were rescinded due to backlash from residents of the La Pine Area.

In this case, the communication issues between government experts (USGS, ODEQ, and Deschutes County) and stakeholders were:

- The urgency expressed by government experts and regulators did not coincide with stakeholders' local knowledge and experience (Ramsayer, 2006). Stakeholders had not experienced negative health impacts from nitrate in drinking water, and the percentage of wells with elevated nitrate was low.
- Government experts were viewed by stakeholders as "arrogant" for expressing too much certainty in their findings and were perceived as talking down to residents (Hofman, 2007)
- Residents (surveyed by the author) felt that they had little input in the LPNDP and that their concerns were ignored.
- Government experts advocated for regulations that were costly to residents (Ramsayer, 2006).
- Stakeholders and government experts approached NOWTS with different knowledge bases (Huddle, 2012).
- Stakeholders disagreed with the study methods used by government experts (Huddle, 2012).

4.3.2 Fate and Transport of Nitrate from Septic Systems, La Pine, OR

The Deschutes County Citizen's Action Group (CAG) reached out to the author to have a third party create a study that was independent from the LPNDP. The author analyzed nitrate in soils at a residence with a septic system and in undeveloped areas of La Pine. Simulations were then created for nitrate transport through soils underneath septic systems (Chapter two).

All parts of the study were affected by the political outcomes of the LPNDP. For example:

- The study was motivated by a citizen's action group who wanted a third party to conduct a study.
- The author came into a funding conflict with ODEQ.
- Stakeholders were asked to participate in the study in an attempt to decrease potential stakeholder controversy.

The author was in communication with stakeholders for the duration of this dissertation, and the author conducted meetings, surveys, and personal visits with stakeholders. Stakeholders received a report from the author after fieldwork was completed.

The author attempted to avoid the communication issues faced by the LPNDP but ran into a different set of communication issues:

- The author was unfamiliar with the methods for communicating with stakeholders.
- The author dressed and acted casually in order to better communicate with stakeholders. However, a casual posture made it difficult for stakeholders to identify the author as an expert and thus to take the author seriously.
- Stakeholders were fatigued by decades of conflict over NOWTS.
- Including stakeholders increased the complexity and the time taken for the dissertation.

There were many negative outcomes of this study (Appendix B). One of the major negative outcomes was low stakeholder participation. Despite the negative outcomes at the end of the author's fieldwork, stakeholders who participated in the dissertation expressed a willingness to fund and aid in future projects conducted by the author.

4.3.3 2008 Update to the Casper Aquifer Protection Plan (2008 CAPP)

The Casper Aquifer Protection Plan (CAPP) was created by local experts and stakeholders in the City of Laramie and Albany County in 2002 to serve as a guidance document for protection of the Casper Aquifer, which provides water for the City of Laramie and private well owners who live to the east of the City of Laramie. The consulting firm Wittman Hydro Planning Associates (WHPA) was hired by the City of Laramie to review and update the CAPP in 2007. WHPA consulted with experts, local government officials, and stakeholders. However, the CAPP update was controversial because:

- The initial drafts of the 2008 CAPP recommended that private well owners should stop using septic systems. In the view of some stakeholders, the recommendation was unreasonable because it was costly, and septic systems were not viewed as a threat to groundwater.
- The CAPP also recommended changing the boundaries of the Casper Aquifer Protection Area (CAPA) to align with political boundaries instead of boundaries based on geology. The CAPA is a geographic area in which land uses were limited to protect the aquifer (WHPA, 2008).

The 2008 CAPP was written in passive voice, using long sentences and ambiguous language. Because the writing was vague, there were many different interpretations of the 2008 CAPP. The writing style use by WHPA was encouraged at the time the 2008 CAPP was written (Strunk and White, 2000). Since then, the

American Planning Association has changed the writing style guidelines for planning documents to plain English, which uses active voice and concise sentences to be more understandable (Noble, 2015).

Another communication issue was that stakeholders had different views of the role of the CAPP. The City of Laramie residents interpreted the CAPP as an advisory document for potential policy actions which would be approved and completed by other groups. The private well owners interviewed viewed the CAPP as a document that would be used to change regulations they would be forced to follow and believed more evidence was needed to justify regulatory changes. Due to these communication issues, a stakeholder filed a formal complaint against WHPA for conducting geology without a license, and the City of Laramie and Albany County created separate CAPP documents (Albany County Planner, 2011).

There was also a physical distance component, in that WHPA was based in Indiana and was acquired by a Texas company the same month the CAPP was submitted to the City of Laramie (Scranton Gillette Communications, 2008). After their involvement in the CAPP, WHPA became less aware of stakeholder perceptions of the 2008 CAPP because WHPA was not physical present in Laramie. Stakeholders in Laramie were less likely to reach out to WHPA with their concerns with the 2008 CAPP because the city government was responsible for making decisions after the CAPP was submitted.

4.3.4 2009/2010 Monitoring in the Casper Aquifer Protection Area (MCAPA)

One of the projects recommended in the 2008 CAPP was increased groundwater monitoring of the Casper Aquifer Protection Area (CAPA). In 2009, the City of Laramie sampled 98 private wells in the CAPA for nitrate. Letters explaining the MCAPA were sent to well owners, asking permission to test their wells before sampling, and individual results were reported to well owners. The results of the MCAPA were presented at public meetings, and a report was disseminated. The local newspaper reported on the results of the MCAPA (Haderlie, 2009). Three wells were found with nitrate concentrations over 10 mg/L. The MCAPA also noted that many of the wells were older or had no construction record, including some of the wells with over 10 mg/L of nitrate. The MCAPA report attributed the nitrate to septic systems (City of Laramie, 2010).

The existing conflict over the 2008 CAPP created communication problems for the MCAPA. In the view of some of the stakeholders interviewed for this study, conflict over the 2008 CAPP decreased the trust between the City of Laramie and private well owners, leading well owners to mistrust the MCAPA report. In the view of some private well owners interviewed, the city used the project to scapegoat them because the MCAPA only attributed nitrate to septic systems. This view was intensified by the depiction of the project in local news with the headline "Nitrate Levels in Well Water Unsafe" (Haderlie, 2010). Private well owners were also concerned that the MCAPA would be used to justify expansion of the sewer system, to require OWTS that could treat for nitrate, and to justify other costly regulations.

The City of Laramie had limited resources for water sampling and was unable to sufficiently address all well owner concerns (City of Laramie, 2010). Private well owners interviewed were concerned that the project pointed at septic systems without considering other nitrate sources (livestock, naturally occurring nitrogen fixation, fertilizer, poorly constructed or maintained wells, in addition to septic systems). Some private well owners also wanted more sampling by a group not related to the city to verify the nitrate levels and to determine whether those levels changed over time (Jarvis, 2014; Starkey, 2017).

The outcomes of conflicts over the 2009/2010 monitoring program were that:

- Private well owners started conducting their own well testing and science projects (Rovani, 2012; Starkey, 2017).
- The City of Laramie could not test private wells in future studies because of heightened mistrust between private well owners and the city, which meant that well owners would not grant the city access to their wells. The city installed and tested monitoring wells instead of private wells in later projects (Hinckley and Moody, 2015).

4.3.5 Albany County Septic System Impact Analysis (ACSSIA)

In 2017, Albany County hired Wenck Associates to determine how much nitrate was removed from wastewater as it infiltrated through the soil, through Quaternary unconsolidated alluvium, and through a portion of unsaturated Casper Formation (the geologic formation that contains the Casper Aquifer). As part of the ACSSIA, water samples were collected beneath a septic system. Sample analysis showed that nitrate concentrations decreased from 69-91 mg/L to 51-56 mg/L as wastewater infiltrated through soils (Wenck Associates, 2019).

Wenck sent the ACSSIA report to the Wyoming Department of Environmental Quality for approval (Wenck Associates, 2019), and the results were presented to City of Laramie and Albany County officials at a public meeting in 2019 (Wenck Associates, 2019; Achs, 2019).

Some stakeholders believed the study was flawed because a hole was bored through a leach field, and the bentonite used to seal the well was not hydrated (Miller, 2019; Stacy and Lidstone, 2019). This caused more nitrate to enter soils and the aquifer, compromising the study results (Miller, 2019).

Wenck intentionally communicated less with the public before the study was completed. When the author approached Wenck in 2018 for an interview, Wenck stated that they were advised by the county not to talk about the ACSSIA until after it was completed. Wenck also did not provide the report to county government officials and stakeholders for review until it was orally presented, so stakeholders felt there was little time to prepare questions and voice concerns.

The Wenck presentation and report provided information in longer detailed format that took stakeholders and experts longer to digest. This communication format protected Wenck scientifically and legally but was not helpful for decision-makers. One decision-maker felt “paralysis by analysis” at the Wenck presentation (Achs, 2019).

People (experts and stakeholders) can only process information at a certain rate (Kobayashi, 1979). When they are not given enough time to process information, they remember the parts that are of greatest concern to them (Murata, 1997). This dynamic created different interpretations of the results of the ACSSIA.

Wenck had a closer connection to Laramie than WHPA did because they were located closer to Laramie, and some Wenck employees had previously lived in Laramie. Because Wenck had local connections, they were notified of stakeholder and expert disagreements with their project, and they responded in a letter to the local newspaper (Stacy and Lidstone, 2019).

4.4 Discussion

The author spoke to some of the GAC experts in La Pine and Laramie about the conflicts. Many GAC experts saw themselves in some aspect as pure scientists, science arbiters or honest brokers who provided unbiased and objective information to stakeholders. At the same time, many GAC experts and stakeholders felt like "politics trampled science." For example, information that was viewed as objective by one GAC expert was not always seen as objective by stakeholders or other GAC experts due to scientific uncertainty and to stakeholder language used in political conflicts. Some GAC experts also took on the role of issue advocates or stakeholders, depending on their connections to the conflict or their personal feelings, mixed with scientific neutrality and politics.

The case studies revealed many communication issues between GAC experts and stakeholders in La Pine and Laramie (summarized in Table 4). These barriers both individually and in combination distanced GAC experts from stakeholders, increasing the chance that stakeholders and GAC experts would misinterpret each other and create conflict. These communication issues show that not only do GAC experts conduct studies but they are also responsible for communicating studies to other people.

Table 4. Communication Issues between GAC Experts and Stakeholders

Communication Issues	Description
Ambiguous Expert Roles	The role that GAC experts were expected to play was not clearly defined. GAC experts changed roles or had multiple roles at the same time. GAC expert were perceived by stakeholders as playing a different role than the role GAC experts thought they were playing.
Language	GAC experts presented their findings using passive voice, which made the information presented wordy and ambiguous. GAC experts who used active voice were seen as advocates or as overconfident in their findings.
Mannerisms	GAC experts are expected to adhere to certain mannerisms and styles, which can be perceived as talking down to stakeholders. Yet being too casual decreased the experts' credibility by breaking social norms.
Information Dumping	GAC experts often present findings in lengthy reports, presentations, and data sets with little time for stakeholders to digest the material. While this protects experts scientifically and legally, more time is needed for experts and stakeholders to process information.
Study Limitations	All studies have weaknesses and limitations. Studies will not be able to address all stakeholder concerns, and many of the concerns will not be known until after the study, when stakeholders have had time to process the information.
External Factors	Many external factors affected the way stakeholders viewed experts. External factors included existing conflict, stakeholder fatigue, undocumented stakeholder concerns, and experts' ability to understand the local context of conflicts.

4.5 Conclusion

There were many communication issues between GAC experts and stakeholders in the La Pine and Laramie conflicts over the issue of groundwater contamination by nitrate from septic systems. These included ambiguous expert roles, language, mannerisms, information dumping, study limitations, and external factors. Many of these communication issues result from the social norms and structures that GAC experts use to communicate with stakeholders and that are used to protect GAC experts legally and scientifically. These communication issues increased the chance that stakeholders and GAC experts would have conflicting interpretations of studies and information.

This chapter makes three policy recommendations based on the La Pine and Laramie case studies:

(1) Joint fact-finding by including stakeholders and stakeholder input more in research projects, or by reviewing information that is more uncertain and contentious to create a common pool of agreed upon information.
(2) As suggested by interviewed GAC experts, simple long-term studies that directly address stakeholder concerns instead of more complex short-term studies.
(3) Concise communication using active voice and plain English (Reitter et al., 2011; Noble, 2015).

More information on this chapter can be found in Appendix C.

4.6 References

Achs, J., 2019, Septic study shows elevated nitrates about Casper Aquifer, City discusses next steps: Laramie Boomerang 11 June, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/septic-study-shows-elevated-nitrates-about-casper-aquifer-city-discusses/article_1c40be77-ba4f-5ea7-a9cf-bb7e3d368e8f.html (accessed June 2019).

Ahola, S., 2017, Why (not) disagree? Human values and the readiness to question experts' views: Public Understanding of Science, v. 26, p. 339–354, doi:10.1177/0963662516637818.

Albany County Planner, 2011, Casper Aquifer Protection Plan: Albany County, Wyoming, 132 p.

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area:

Haderlie, C., 2009, City tests private wells: Laramie Boomerang 3 December, Laramie, Wyoming, https://www.laramieboomerang.com/news/city-tests-private-wells/article_0c8cfa05-c10f-5a44-8361-a01865f60a4f.html (accessed January 2020).

Haderlie, C., 2010, Nitrate Levels in Well Water Unsafe: Laramie Boomerang 14 July, Laramie, Wyoming, https://www.laramieboomerang.com/news/nitrate-levels-in-well-water-unsafe/article_67baf722-bac4-56e7-9e87-85db0bc5aacd.html

Hinckley, B., and Moody, C., 2015, Phase II - Laramie Monitor Well Project Report: City of Laramie, 145 p., https://www.cityoflaramie.org/DocumentCenter/View/8384/Phase-II-Report-final-complete (accessed February 2019).

Hofman, J., 2007, Septic Smiles: The Bulletin 1 January, Bend, Oregon, https://www.bendbulletin.com/opinion/septic-smiles/article_13f1a414-6d37-5ec6-8af7-566611781b84.html

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

Kobayashi, S., 1979, Effects of Priority Instructions on Processing of Picture Items: Psychological Reports, v. 45, p. 919–922, doi:10.2466/pr0.1979.45.3.919.

Lackey, R.T., 2004, Normative Science: Fisheries, v. 29, p. 38–39.

Stacy, M., and Lidstone, C., 2019, Stacy/Lidstone: Hydrologists stand by work: Laramie Boomerang 21 December, Laramie, Wyoming, p. 3. https://www.laramieboomerang.com/opinion/guest_column/stacy-lidstone-hydrologists-stand-bywork/article_539f898b-31b1-556e-bf4b-021ecf994c4b.html

Miller, C., 2019, Miller: Hinckley's aquifer arguments lack merit: Laramie Boomerang 8 December, Laramie, Wyoming, https://www.laramieboomerang.com/opinion/guest_column/miller-hinckley-s-aquifer-arguments-lack-merit/article_90e4449b-68a0-5655-ba4e-4a5d9191dfb2.html (accessed December 2019).

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Murata, A., 1997, On information dumping phenomenon in free recall - Effects of priority instructions on free recall of pictures and words: IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, v. E80-A, p. 1729–1731.

Noble, B.K., 2015, Zoning Codes in Plain English: Zoning Practice, American Planning Association, p. 8.

Pielke, R.A., 2007, The honest broker: Making sense of science in policy: Cambridge, UK, Cambridge University Press.

Ramsayer, K., 2006, Residents quiz geologists on La Pine water: The Bulletin 21 December, Bend, Oregon, p. 2.

Reitter, D., Sycara, K., Lebiere, C., Vinokurov, Y., Juarez, A., and Lewis, M., 2011, How Teams Benefit from Communication Policies: Information Flow in Human Peer-to-Peer Networks:

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Scranton Gillette Communications, 2008, Layne Christensen Acquires Wittman Hydro Planning Associates: Water & Wastes Digest, https://www.wwdmag.com/layne-christensen-acquires-wittman-hydro-planning-associates (accessed January 2020).

Starkey, R., 2017, Overview of the Casper Aquifer Protection Network Groundwater Sampling Program: presented to the Albany County Board of County Commissioners and to the Albany County Planning and Zoning Commission.

Strunk, W., and White, E.B., 2000, Elements of Style: Pearson.

Watershed Professionals Network, 2002, Little Deschutes River Subbasin Assessment: Upper Deschutes Watershed Council.

Wenck Associates, 2019, Albany County Septic System Impact Analysis: Wenck Associates, Albany County, Wyoming Department of Environmental Quality, 269 p.

Williams, J.S., Morgan, D.S., and Hinkle, S.R., 2007, Questions and Answers About the Effects of Septic Systems on Water Quality in the La Pine Area, Oregon:

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

5. RESIDENT SCIENCE

5.1 Introduction

There have been decades of political conflict in La Pine, OR and Laramie, WY over the environmental issue of groundwater contamination by nitrate from onsite wastewater treatment systems (NOWTS). NOWTS occurs when nitrate from septic systems (and other types of onsite wastewater treatment systems or OWTS) contaminates groundwater which is used as a drinking water source. Nitrates are a health concern because nitrate increases the potential of methemoglobinemia in infants, though it has less impact on older populations (Gehle, 2013).

In both La Pine and Laramie, over 95% of private wells had nitrate concentrations below the limits set for public drinking water supplies (the Safe Drinking Water Act 1974 limits nitrate to 10 mg/L). Conflicts occurred because stakeholders had a spectrum of views ranging from nitrate being a large and growing problem to there being no contamination from OWTS. Stakeholder views were influenced by their financial, health, and environmental perspectives.

All stakeholders wanted regulation to protect groundwater, but they disagreed on the type of regulation, enforcement of regulations, and who would pay the cost of regulations (Chapter three).

The political conflicts in La Pine and Laramie were unique because scientific research that was conducted by non-governmental organizations, resident experts, or residents (resident science) was credible enough to be part of the discourse over NOWTS, affecting regulatory actions. In the Western US, the vast majority of scientific research was conducted or funded by governments, based on a review of 51 communities with NOWTS issues (Appendix B).

Resident science is when stakeholders and experts conduct scientific research in their capacity as residents of a community, and resident scientists are not affiliated with or funded by a government or an academic institution. This chapter explores two questions about resident science:

1. Why did stakeholders (and experts) create resident science?
2. Why was resident science widely accepted among stakeholders (and local experts)?

5.2 Methods

The information on resident science was gathered from surveys, interviews, and communications the author had with stakeholders in La Pine and Laramie (Appendix B). Where possible, communications were corroborated with local newspaper articles, journal articles, US Geological Survey reports, agency reports, consultant reports, city/county/non-governmental organization documents, laws, websites, and academic graduate theses.

Case studies were created based on three resident science projects in La Pine and Laramie. One case study from La Pine on *Groundwater Protection and the La Pine Basin*. Two case studies from Laramie on the CAP Network Groundwater Sampling Program and on “Jack and Jill Went Up the Hill to Fetch a Pail of… Nitrates!!!” Although there were other resident science projects in La Pine and Laramie, these three were mentioned the most in communications with stakeholders and had minimal government involvement.

The results section summarizes each case study, exploring the background leading up to resident science, residents' motivation to take on the project, and the major conflicting perspectives stakeholders had of NOWTS in La Pine and Laramie. The discussion synthesizes the case studies, focusing on why resident science was created and how resident science shaped policy.

5.3 Results

5.3.1 *Groundwater Protection and the La Pine Basin*

Groundwater Protection and the La Pine Basin was a study conducted by members of the Deschutes County Citizen's Action Group (CAG), who analyzed publicly available data and results from the La Pine National Demonstration Project (LPNDP; Huddle, 2012). The LPNDP was a series of projects on NOWTS in La Pine conducted by Deschutes County and other government agencies between 1999 and 2007. The projects included studies of OWTS, hydrology, and nitrate contaminant transport (Rich, 2005). CAG was a non-governmental organization (NGO) in La Pine whose goals were "To preserve quality of life, protect individual and community rights, as well as to conserve rural identity and natural resources."

Having analyzed data from the LPNDP, CAG members disagreed with its findings for a range of reasons. CAG members distrusted LPNDP experts because the LPNDP findings did not agree with local knowledge, causing suspicion about the quality of the data analysis. LPNDP experts were viewed as issue advocates by residents because regulations proposed by LPNDP experts were expensive and residents were expected to pay those costs. Finally, years after the LPNDP concluded, expert predictions of further groundwater contamination of groundwater did not come to pass. Through the whole process, government experts communicated poorly with stakeholders. Government expert communication is covered in more detail in Chapter four.

Based on stakeholder concerns with the LPNDP, CAG created the resident science project *Groundwater Protection and the La Pine Basin*. Resident science was conducted by resident experts who were members of CAG. The resident experts had graduate educations (some were related to water, others were not) or had worked in water-related fields or for government agencies. Data from the LPNDP was reanalyzed and updated with new data on groundwater from other public sources.

La Pine Area residents had positive views of *Groundwater Protection and the La Pine Basin*, while state regulators had more neutral views of it.

Table 5. Views of *Groundwater Protection and the La Pine Basin* (Personal Communication)

Rural Residents (includes Experts)	State Regulator
La Pine area residents (spoken to or surveyed by the author) liked the CAG project because it aligned with their knowledge and experience. Residents trusted CAG more than government experts.	State regulators' view of NOWTS changed over time as more data came out on the issue. Regulators were initially concerned by NOWTS in the 2000s (Ramsayer, 2006), but by 2017 they had stepped back as new information came out (Hammers, 2012). A regulator spoken to in 2017 saw the CAG project as validating the LPNDP, since the CAG findings agreed with the 1999 LPNDP simulation as well as with groundwater data collected after the LPNDP was published.

Prior to their disbanding in 2019, CAG used *Groundwater Protection and the La Pine Basin* to explain their perspective of NOWTS to stakeholders.

5.3.2 The CAP Network Groundwater Sampling Program

The Casper Aquifer Protection Network (CAP Network) has been conducting annual water sampling of private wells since 2011. The wells belong to private well owners who live east of the City of Laramie and whose only source of water is the Casper Aquifer (Groundwater Foundation, 2017). Other CAP Network activities include studying nitrate concentrations in rural wells before and after the wells had been replaced with new wells which were sealed to the top of the water bearing interval (Starkey, 2017). CAP Network's well water sampling program was created and conducted by an unpaid geologist who is also a private well owner and had samples tested at an accredited laboratory (CAP Network, 2011).

The CAP Network is an NGO composed of over 200 private well owners who live east of Laramie, including some members who are water experts from the University of Wyoming or the community of local water consulting firms, as well as local government officials. The CAP Network's mission is "to protect the Casper Aquifer and to preserve property rights for now and for the future" (CAP Network, 2011).

There have been conflicts over protection of the Casper Aquifer since the 1990s (Jarvis, 2014). The event that motivated the formation of the CAP Network program was a City of Laramie program that sampled private wells east of Laramie in 2009 and 2010 (City of Laramie, 2010). The private well owners interviewed disagreed with the City of Laramie well sampling project because:

- There was existing mistrust between private well owners and the City of Laramie from previous city regulations (Chapters three and four).

- The city well sampling project concluded that nitrate came from septic systems owned by private well owners (City of Laramie, 2010). Private well owners disagreed because the nitrate could be from other sources — livestock, natural nitrogen fixation, and poorly constructed or maintained wells and septic systems.
- Private well owners wanted to determine for themselves the extent of nitrate impacts. The city was viewed as an issue advocate, since the city sampling could be used by the city to regulate private well owners.
- Private well owners believed more sampling over time was necessary in order to confirm the city's results and determine historical trends (Jarvis, 2014).

In stakeholder interviews, views of the CAP Network program were divided along similar lines as the City of Laramie program. Interviewed private well owners supported the CAP Network program, while interviewed City of Laramie residents and experts had negative views of the CAP Network program (Table 6).

Table 6. Views of the CAP Network Well Sampling based on Interviews.

<table>
<tr><th>Interviewed Private Well Owners (includes Experts)</th><th>Interviewed City of Laramie Residents (includes Experts).</th></tr>
<tr><td>The CAP Network well sampling had credibility because:
Private well owners viewed the program as run by friends and neighbors they trusted and the CAP Network expert was viewed as an honest broker.
Private well owners trusted the CAP Network expert to protect data. Private well owners were concerned that data would be used to harass well owners, or that the city would use the data to regulate or force well owners to make expensive renovations.
The program directly addressed private well owner concerns about poorly constructed and maintained wells (Starkey, 2017).
The project was endorsed by the Albany County Board of Commissioners and the Albany County Planning and Zoning Commission.
CAP Network information was part of the public record, disseminated in a newsletter provided to CAP Network members, and presented at meetings and educational events.</td><td>The CAP Network well sampling project was less credible because:
City residents did not trust the CAP Network because it was often the political opponent of city residents and experts over Casper Aquifer protection issues and the CAP Network expert was viewed as an issue advocate.
City residents viewed the CAP Network well sampling program as having less review than scientific data from governments, consultants, or academics.
City residents attached a social stigma to the CAP Network well sampling program data because it was not accessible online (though it was available through other means; see other side of Table 6).
Science conducted by government or by consultants for governments was often accessible online.
The measure of accessibility was whether scientific data could be directly accessed by a www.google.com search and was not behind a paywall.</td></tr>
</table>

At the time of this dissertation, the CAP Network program is ongoing and information is used by the CAP Network for outreach, education, and advocacy.

5.3.3 "Jack and Jill Went Up the Hill to Fetch a Pail of… Nitrates!!!"

The same conflicts over NOWTS in Laramie that motivated the CAP Network to start its well sampling program also motivated a student (who lived in a residence east of Laramie that has a private well) to study nitrate for his science fair project. The science fair project won a Junior Division Sweepstakes Award of Exceptional Merit from the 2011 State Science Fair (University of Wyoming, 2011).

The student saw a data gap in the City of Laramie 2009/2010 water monitoring program, since the city did not test for background groundwater nitrate concentrations that were not impacted by septic systems (Rovani, 2012).

The student tested background groundwater nitrate concentrations in two science fair projects: (1) in 2011 the student collected water samples from local springs (that were miles from residences) and had them tested for nitrate; (2) in 2012 the student leached nitrate from soils near plants in undeveloped areas. The student found that undisturbed springs had low nitrate concentrations (2 mg/L) and leachate from soils had high concentrations of nitrate (200 mg/L) (Rovani, 2012).

When the author interviewed stakeholders in Laramie, the science fair project was mentioned less by stakeholders than the CAP Network Groundwater Sampling Program. The science fair project was also mentioned less by City of Laramie residents.

Table 7. Views of the Student Science Fair Project based on Interviews.

Interviewed Private Well Owners (includes Experts)	Interviewed City of Laramie Residents (includes Experts)
Interviewed private well owners had positive views of the science fair project because: • The project directly studied naturally occurring nitrate, a topic that was of direct interest to private well owners. • Private well owners were proud that a minor from their neighborhood completed a high quality science project. • The project showed that aquifer science was not the exclusive domain of experts.	The science fair project was mentioned less by interviewed stakeholders who were city residents because: • The science fair project was lumped with the CAP Network Groundwater Sampling Program. • While the science fair project showed background nitrate, it did not disprove that nitrate could come from septic systems.

5.4 Discussion

5.4.1 Resident Science Creation

These case studies reveal many factors that led stakeholders to conduct resident science in La Pine and Laramie.

All the resident science case studies in La Pine and Laramie were created to build upon or verify the work of projects conducted previously by experts and consultants affiliated with governments. Stakeholders (and experts) had a level of distrust of government experts (who were viewed as issue advocates) because government expert views conflicted with local political views, values, interests, and stakeholder knowledge. Both La Pine and Laramie have a decades-long history of mistrust between experts and stakeholders that promoted the development of resident science projects as a response to government studies viewed by residents as unfair or inaccurate (Huddle, 2012; Jarvis, 2014).

In all of the case studies, there were data gaps or stakeholder concerns about the science that were not sufficiently addressed by experts. Based on reports and communications with government experts, they felt that these data gaps had already been sufficiently filled, based on their expert knowledge. They also asserted that the studies followed standard practices in the field and were created by standard practices used by experts. Experts also pointed out that they were limited by resource or political constraints (Chapter three).

There were also enough resources to conduct resident science. Resources include financial resources, education, active community members who support the projects, access to equipment or data, and access to experts. These resident science projects were conducted by residents who were experts and had the knowledge to find data gaps in available information. Resident scientists were also able to communicate with other resident experts—professors, scientists, hydrogeologists, and engineers—some of whom were also well owners in Laramie, or residents with graduate degrees and work experience in La Pine.

5.4.2 Impact of Resident Science

Resident science continues to have a direct impact on politics in La Pine and Laramie. It continues to be used by residents and elected officials to successfully argue for or against regulations and policies (Bendtsen, 2020).

In the case studies, stakeholders (including experts) had mixed views of resident science (Table 8).

Table 8. Stakeholder Views of Resident Science

For Resident Science	Against Resident Science
• Resident science was created by stakeholders and experts trusted by stakeholders to conduct science. • Resident science correlated with local stakeholder knowledge and experience. • Resident science directly addressed stakeholder questions and concerns. • Stakeholders felt ownership or were proud of resident science.	• Resident science was created by people stakeholders mistrusted or who were political opponents. • Resident scientists were viewed as *issue advocates* instead of as *honest brokers*. • Stakeholders mistrusted methods, results, or data handling practices.

5.5 Conclusion

Resident science is not unique to environmental conflict, but it is often not widely accepted by stakeholders or has little policy impact (Kurki, 2016). In communications with stakeholders in La Pine and Laramie, resident science was taken seriously enough by stakeholders to significantly impact politics. Though resident science impacted politics in La Pine and Laramie, there is varied stakeholder acceptance of resident science. Some stakeholders trusted resident science because it was created by experts who they trusted, it correlated with local knowledge, and it directly addressed their concerns. Resident science was mistrusted because it was created by the stakeholders' political opponents or by people they mistrusted, and because they mistrusted resident science methods or results.

Based on resident science case studies, four factors led to the creation of resident science in La Pine and Laramie: (1) stakeholders mistrusted studies conducted by experts and regulators; (2) stakeholders had the knowledge to find data gaps; (3) stakeholders had sufficient funding, expertise, and equipment to conduct their own research; (4) resident science built upon or verified the work of contentious government studies.

This chapter recommends that resident science be further leveraged in NOWTS conflict through the use of joint fact-finding. Resident science had multiple positive outcomes because it empowered stakeholders and supported alternative views of NOWTS. As part of the joint fact-finding, resident scientists could work together with opposing stakeholders (and experts) to address the outcomes of resident science that escalate conflicts. An example of a possible compromise for the CAP Network Groundwater Sampling Program would be for the CAP Network and opposing stakeholders to develop data use practices that address private well owner concerns about data being used against them while also addressing opposing stakeholder concerns about resident science taking place outside of traditional science circles (academia, government, consultants, etc.). Potential strategies might involve using confidentiality agreements to give opposing experts access to data while protecting the confidentiality of the data, or setting community rules for the use of science in political settings.

More information on this study can be found in Appendix D.

5.6 References

Bendtsen, D., 2020, Commissioners vote 2-1 on contentious zoning change: Laramie Boomerang 7 January, Laramie, Wyoming. https://www.laramieboomerang.com/news/local_news/commissioners-vote-2-1-on-contentious-zoning-change/article_495f03ad-c6f2-5296-8a99-075ddcfd541f.html

CAP Network, 2011, CAP Network News Letter February 2011:

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area:

Gehle, K., 2013, ATSDR Case Studies in Environmental Medicine: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry WB2342, 135 p.

Groundwater Foundation, 2017, 2017 Groundwater Guardian Profiles: Groundwater Foundation, 70 p.

Hammers, S., 2012, Nitrate levels show no pattern: The Bulletin 5 February, Bend, Oregon, p. 2.

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

Kurki, V., 2016, Negotiating Groundwater Governance: Lessons from Contentious Aquifer Recharge Projects: Tampere University of Technology, 169 p., https://tutcris.tut.fi/portal/files/6149146/Kurki_1387.pdf.

Ramsayer, K., 2006, Residents quiz geologists on La Pine water: The Bulletin 21 December, Bend, Oregon, p. 2.

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Starkey, R., 2017, Overview of the Casper Aquifer Protection Network Groundwater Sampling Program: presented to the Albany County Board of County Commissioners and to the Albany County Planning and Zoning Commission.

University of Wyoming, 2011, Laramie, Greybull Students Top State Science Fair Winners: University of Wyoming, http://www.uwyo.edu/uw/news/2011/03/laramie,-greybull-students-top-state-science-fair-winners.html (accessed June 2020).

6. GENERAL CONCLUSION

The purpose of this dissertation is to better understand the connection between politics and science in conflicts over the environmental issue of groundwater contamination from nitrate from onsite wastewater treatment system (NOWTS). The expectation is that lessons learned from this dissertation could be applied to other environmental science conflicts.

The author explored four parts of the conflicts in La Pine and Laramie. The author worked with local non-governmental organizations to conduct a soil study in La Pine. The soil study found that NOWTS was reduced by 22-40% upon reaching groundwater (Chapter two). In the process of creating the soil study, the author became a part of the conflicts in La Pine. Conflict assessments of NOWTS conflicts in La Pine, OR and Laramie, WY were created to understand the history and setting so as to better navigate NOWTS conflicts (Chapter three). The conflict assessments revealed that the way government experts, consultants, and academics communicated with stakeholders often escalated conflicts (Chapter four). Finally, the dissertation explored science conducted by residents (experts) in La Pine and Laramie. Resident science occurs in many environmental conflicts but often has little impact (Kurki, 2016). However, in La Pine and Laramie, resident science had major impacts on the conflicts (Chapter five).

General conclusions were created by synthesizing Chapters two through five together:

(1) NOWTS is a highly complex topic with a high degree of variation based on local conditions, which creates a high degree of uncertainty. These

uncertainties are a source of conflict for stakeholders and experts, and are similar to other "wicked" environmental issues (Rittel and Webber, 1973).

(2) Experts often cannot directly address stakeholder questions due to limitations they face themselves — limited funding, understanding of stakeholder knowledge, permission, time, access to equipment, and communication issues.

(3) The practices used by experts protected them legally and scientifically but increased the time stakeholders (and experts) took to process information, and there were more varied interpretations of expert projects.

(4) Stakeholders were more likely to trust science and resident science when it was created by people they knew and trusted.

(5) Urban versus rural interests split stakeholders in NOWTS conflicts in La Pine and Laramie. Though the structure of the divide was different in each location, the values associated with the urban-rural divide were similar.

(6) As stakeholders participated in conflict, they became more knowledgeable about the science and politics behind the issues. Stakeholders also built self-perpetuating opinions of each other that color their interactions. Specific stakeholder views changed over time, but more general interests and values did not.

(7) As stakeholders participated in conflicts, they became more fatigued by the conflict over time. Symptoms of fatigue ranged from not having the resources to continue the conflict to general frustration over continued unresolved issues.

Some of the conclusions from NOWTS conflicts in La Pine and Laramie are transferable between La Pine, Laramie, and other environmental conflicts, but other lessons are not transferable. When experts are brought in to conduct studies, they should acquire an in-depth understanding of the politics and talk to stakeholders involved in environmental conflicts, in order to build trust and design more effective projects.

6.1 Policy Recommendations

Though there continue to be political conflicts in La Pine and Laramie, both communities have demonstrated the capacity to work through conflict. However, stakeholders and experts in La Pine and Laramie have maintained a history of having different interpretations of NOWTS projects (Chapter four and five). Some community members have been leery of mediation or outside help. One expert interviewed in the City of Laramie stated, “Mediation supports the status quo.” Therefore, any recommendations in this dissertation must be discussed with the community and adjusted to fit their situation. Everyone should check with local regulators and experts before doing anything based on the information in this dissertation.

Two general policy recommendations for NOWTS conflicts in La Pine and Laramie are presented. Because the conflicts are constantly evolving, many of the more specific recommendations made in the process of writing this dissertation are already outdated.

The first is to expand the scope of contentious issues by placing the issues in a wider context (Ostrom, 1990; Heikkila and Gerlak, 2005). For example, in Laramie, because NOWTS is part of the wider issue of aquifer protection, there is more sustained interest in the conflict. In La Pine, because NOWTS was not part of a wider context, stakeholders lost interest when there was less regulatory action on the issue.

The second recommendation is to build coalitions with other groups that have similar concerns or interests. Coalitions could be strengthened by working together on smaller activities (Table 9) or on issues where there is widespread agreement to create “small wins.” Small wins can then be leveraged to build trust and momentum for larger actions. As there are more small wins, coalitions can be expanded to include more diverse viewpoints (O’Brien, 2012).

These strategies are long-term and would require committed community leaders willing to mediate conflicts and push for action. For communities in which there is a high degree of stakeholder fatigue (such as La Pine), "small wins" can be obtained from much smaller projects that work toward larger political changes. For example, public outreach and education build wider stakeholder interest in the issue.

Table 9. Small Actions for "Small Wins"

Small Action	Description
Small Actions	Every project is created by many small steps. These steps can be used as goals or milestones for action.
	Example: tabling at an event, having a conference call with another group, conducting in-person meetings, applying for a grant.
	Example: checking the status of wells and septic systems.
Joint Fact-Finding	Having members from groups that have multiple perspectives of a conflict cooperate to settle factual disputes.
	Example: experts and stakeholders working together to settle issues where expertise is contested or if there are dueling experts.
	Example: groups working together to form a common pool of information that is widely accepted by stakeholders.
Limited Public Warnings	Instead of a public warning, health care providers would only warn pregnant women and caretakers of infants (0-1 year old) who use private wells. The warning would include well testing, breast feeding, and using alternate sources of water or bottled water for baby formula. The warning would be given to reduce chances of infant nitrate consumption and reduce risk of methemoglobinemia. The warning would be limited since older groups are less affected by nitrate (EPA; L'Hirondel and L'Hirondel, 2001; Greer, 2005).
Sole Source Aquifer Program	An EPA program that designates a geographic area within which the EPA will review all projects that receive federal funding to determine whether the projects pose a threat to aquifers. The program would be used to legally define the aquifer and increase community awareness. Anyone can petition the EPA for this program. A potential petition for La Pine is included in Appendix E.
Grants	Grants can be used to leverage larger projects, including studies and infrastructure construction, and can potentially lower costs.

6.2 Science Recommendations

The science and policy of NOWTS issues are tightly interwoven. Science shapes stakeholder perspectives, which are used to create policy, and that policy in turn guides and limits scientific research.

The following recommendations are based on the idea that knowledge creation is a collaborative process and involves collaborative learning and forming a common pool of knowledge (Daniels and Walker, 2001; Ansell and Gash, 2007; Weber, 2013). Expert studies are part of "civic" science because their main audience is the public, not experts, and they are used to make policy (Clark and Illman, 2001).

(1) Experts should increase their communication with stakeholders in order to better understand stakeholder concerns, avoid miscommunication, and integrate stakeholders' local knowledge.
(2) Experts and resident scientists should interact more with each other to elevate the credibility of resident science and conduct better science.
    I. Experts could train new resident scientists.
    II. Experts could review resident science.
    III. Trust should be built between experts and resident scientist so that compromises can be reached on scientific methods and practices.
(3) Experts should treat the public as the main audience of their work instead of academics or other experts. Experts should use plain English instead of a technical writing style.
(4) Expert studies should be small, simple, and direct to be both technical and understandable to stakeholders.
(5) Experts should use joint fact-finding to fill in or find stakeholder and expert data gaps.
(6) Experts should be professional and objective, but not to the extent that stakeholders are alienated by their manner and style.
(7) Experts must take into account stakeholder concerns, which are subjective and based on interests, values, and beliefs.
(8) Communications must remain open between experts and stakeholders long after studies have been conducted.

Stakeholder-expert communications warrant further investigation, as many of these recommendations require greater time investment by both stakeholders and experts. This is problematic when experts are hired from outside the community for a limited time. NOWTS conflicts have a long history in La Pine and Laramie, making it difficult to navigate stakeholder concerns and controversy. Lessons learned from these conflicts could be used to avoid or prevent problems experienced in La Pine and Laramie.

6.3 Example Summaries

Two summaries have been written based on field work conducted in La Pine and Laramie. The goal of the summaries is to distill as much information as possible into a small amount of space, and the summaries are an attempt to implement some of the science recommendations made in this dissertation. These summaries will be provided to stakeholders, as will a link to the full dissertation document.

Nitrate and Septic Systems in La Pine
Conflict Assessment and Soil Study

By David Demaree
Environmental Science PhD Candidate, Oregon State University

Nitrates in some privately owned wells in the La Pine area were found to be over 10 mg/L in 1979, and some wells continue to have elevated nitrate concentration (Fig. 1)(Cole, 2006).

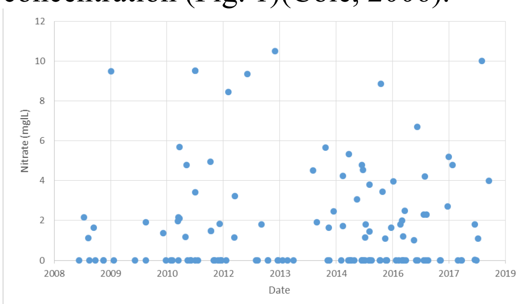


Fig. 1. Nitrate in Well Water 2008-2018

The La Pine area has a history of political conflicts over nitrate in groundwater. Conflicts tend to be between regulators and residents of the La Pine area.

Deschutes County and the Oregon Department of Environmental Quality (ODEQ) are required to take action when nitrate in groundwater is over 10 mg/L (OAR 340-40), because nitrate can cause methemoglobinemia in infants and can cause algal blooms in lakes and streams (Comly, 1945; Schlesinger and Bernhardt, 2013). Regulators attribute the nitrate in groundwater to contamination from the ~7000 septic systems used by rural residents to treat their wastewater (Fig. 2) (Morgan et al., 2007).

Nitrate forms as water from septic systems infiltrates through soils and organic matter is decomposed by microorganisms to form nitrate. Microorganisms can also remove nitrate by forming nitrogen gas, but the process is slower than nitrogen formation (Grady et al., 2011; Madigan et al., 2015). Other processes can also remove nitrate.

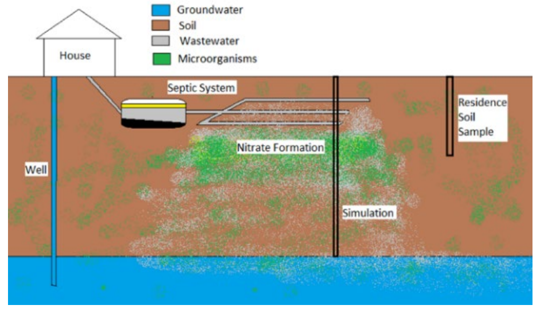


Fig. 2. Septic System Diagram

Rural residents were less concerned with nitrate contamination of groundwater because the majority of wells had low nitrate concentrations, concentrations were not increasing (Fig. 1), and there were no visible impacts.

Nitrate conflicts were most contentious around 2008, when an ordinance required residents to use septic systems capable of treating nitrate (Ordinance 2008-021). Residents disagreed with the ordinance because the systems were too expensive for many residents. Residents also disagreed with the studies on which the regulations were based, since the studies conflicted with local knowledge, and experts did not communicate well with residents or pay attention to resident concerns (Huddle, 2012).

After 2008, the conflict settled down as regulators involved in decision-making created less contentious regulations and stakeholders became fatigued by the conflict.

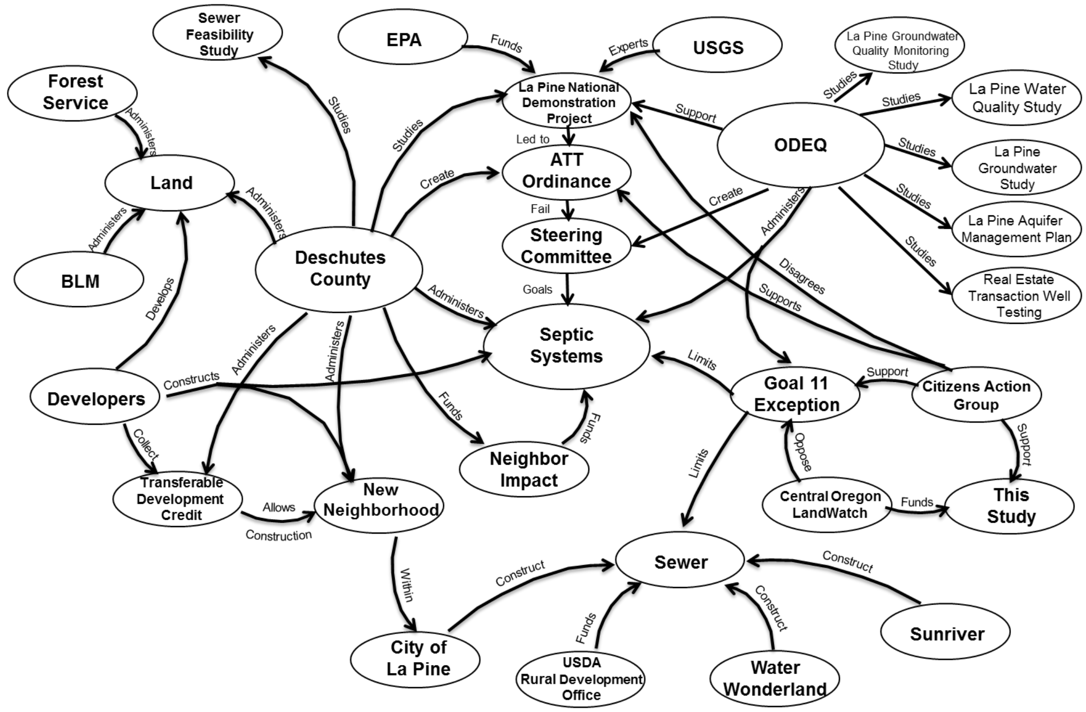


Fig. 3. Groups, Studies, and Regulations in La Pine Nitrate Conflicts 2000-2019

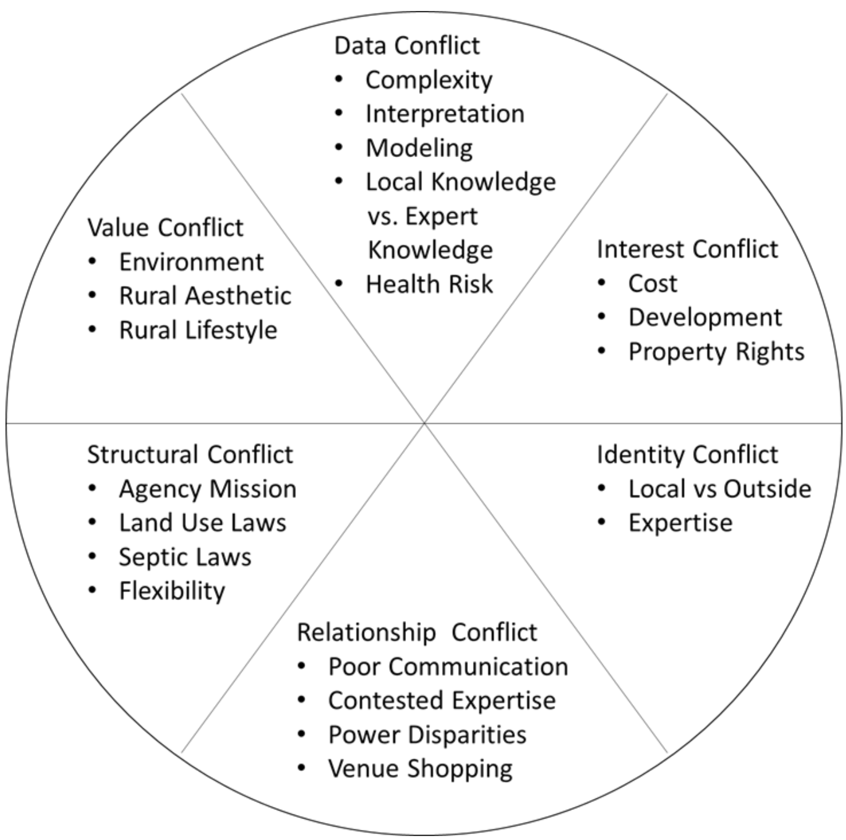


Fig. 4. Facets of the Conflicts in La Pine 2000-2019

Conflict Assessment

An assessment was conducted of the conflict over nitrate in La Pine in 2017. At the time, the conflict had mostly settled down because stakeholder groups were fatigued by the conflict and the government did not have the resources to continue the conflict. There was some continued conflict between developers and regulators over the Transferable Development Credit program (Shumway, 2019).

In 2017, septic systems were approved on a case-by-case basis by Deschutes County and ODEQ. Regular and nitrate-treating septic systems were approved depending on the situation.

The communities of La Pine and Sunriver had also increased the reach of municipal sewer systems within their boundaries (Hamway, 2018).

Policy Recommendations

In 2019, the conflict had reached a resolution of sorts. No one was happy with the outcome, but stakeholders were satisfied enough that they were willing to live with a case-by-case septic approval system.

Two strategies are suggested to decrease conflict for future projects. The first includes having more diverse stakeholder groups in the decision-making process to build greater consensus.

The second strategy involves starting with smaller projects or regulations to build trust and momentum for larger projects and regulations that have greater impacts on the community, instead of starting with large, high-impact regulatory changes.

Soil Study

In 2017, an Oregon State University graduate student conducted a nitrate study at the behest of the Deschutes County Citizen's Action Group and Central Oregon LandWatch, who wanted a third-party study.

A soil study was conducted that found that a rural residence with a septic system had higher nitrate concentrations than undeveloped areas (Fig. 5).

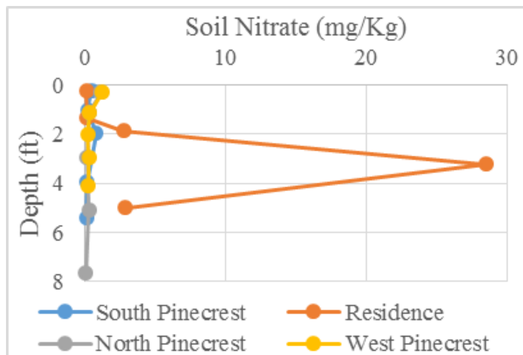


Fig. 5. Soil Nitrate Concentrations

Because the source of the nitrate could not be determined, a model was created to simulate nitrate transport from septic systems. The model determined that 24-40% of nitrate was removed from wastewater as it passed through soils (Fig. 6).

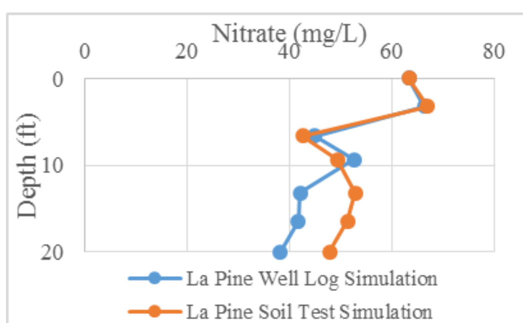


Fig. 6. Soil Nitrate Concentrations

This study only looked at soils above the water table. More research is needed on other factors that will further reduce nitrate concentration before it reaches wells. Some factors not tested in the soil study include the dilution of wastewater by groundwater, denitrification in groundwater, and nitrate plume mapping.

References

Cole, D.R., 2006, Groundwater Quality Report for the Deschutes Basin, Oregon:, 59 p.

Comly, H., 1945, Cyanosis in Infants Caused by Nitrates in Well Water: Journal of the American Medical Association, v. 129, p. 112–116.

Grady, C.L.P., Daigger, G.T., Love, N.G., and Filipe, C.D.M., 2011, Biological Wastewater Treatment: CRC Press, 1022 p.

Hamway, S., 2018, $25M La Pine infrastructure project moves forward; Project to bring nearly 300 lots onto water, sewer system and expand capacity: The Bulletin 28 February, Bend, Oregon https://www.bendbulletin.com/localstate/6120818-151/25m-la-pine-infrastructure-project-moves-forward (accessed April 2019).

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Madigan, M., Martinko, J., Bender, K., Buckley, D., and Stahl, D., 2015, Brock Biology of Microorganisms: Pearson Education Limited, 1030 p.

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Schlesinger, W.H., and Bernhardt, E.S., 2013, Biogeochemistry: An Analysis of Global Change: Elsevier, Academic Press, 672 p.

Shumway, J., 2019, La Pine builder calls Deschutes County groundwater plan a failure: The Bulletin 11 April, Bend, Oregon, http://www.bendbulletin.com/localstate/7079886-151/builder-questions-deschutes-county-groundwater-plan (accessed October 2019).

Assessment of Conflicts over the Casper Aquifer in Laramie, WY

By David Demaree
Environmental Science PhD Candidate, Oregon State University

The Casper Aquifer is the source for 60% of the City of Laramie's drinking water and the sole water source for rural residents who own private wells to the east of Laramie.

The Casper Aquifer is in the Casper Formation, which is exposed to the east of the City of Laramie and dips at 3-5 degrees under the City of Laramie. The Casper formation is composed of layers of limestone and sandstone. The confined sandstone layers are tapped as a water source. The Casper Formation is covered by the Satanka Shale (WHPA, 2008).

There have been ongoing conflicts in the Laramie area over aquifer protection since the 1990s. Conflict assessments were created for the political conflicts over the Casper Aquifer in the 1990s and 2013 (Jarvis, 2014). A follow-up conflict assessment was created in 2018 to build upon the previous conflict assessments. As part of the conflict assessment, stakeholders in Laramie were interviewed. Although the assessment makes generalizations from those interviewed, stakeholders have diverse views. The author also aided the CAP Network with an event and received in-kind services. The CAP Network is a group composed primarily of private well owners whose sole source of water is the Casper Aquifer.

During the 1990s, the City of Laramie, Albany County, stakeholders, and local water experts created a Wellhead Protection Plan and delineated the Casper Aquifer Protection Area (CAPA). The CAPA limits land use in the Casper Aquifer recharge area east of Laramie to protect the aquifer from contamination.

During the 1990s, conflicts occurred over business development that could potentially contaminate the aquifer. Additional conflicts occurred between experts over the geology of the aquifer and contaminant flow.

The concerns was that hazardous materials used by the businesses and septic systems used for rural wastewater treatment would not fully treat wastewater, thus contaminating the aquifer.

The conflicts continued to evolve during the 2000s. The Casper Aquifer Protection Plan (CAPP) was created by volunteers from the community in 2002, and the City of Laramie created an ordinance based on the plan. Conflicts over potential aquifer contamination expanded to include residential developments and existing residences on the CAPA. These conflicts were most contentious over a 2008 update to the CAPP, and the City of Laramie and Albany County split creating separate CAPPs and ordinances for the Casper Aquifer (WHPA, 2008; Albany County Planner, 2011). Many different stakeholder groups were drawn into the 2008 conflict.

In the 2010s, conflicts were not as heated as in the 2000s but would flare up occasionally over construction on the CAPA. Part of the reason there was less conflict was that a series of bills in the state legislature reduced the jurisdictional overlap between City and County governments in areas outside city limits (2013 HB 85, 2018 HB 14).

Stakeholders in Laramie tend to be split on Casper Aquifer Protection along the urban-rural divide. Urban groups are associated with residents and the government of the City of Laramie. Rural groups are associated with private well owners and the government of Albany County (Jarvis, 2014).

Urban groups tend to favor stricter enforcement of aquifer protection measures to have the cleanest water possible. Rural residents want aquifer protection regulations but want them to be balanced by the financial cost of regulations on private well owners and impacts on property rights.

There was a power disparity between urban and rural residents. Until bills passed in the state legislature in 2013 and 2018, the City of Laramie had the ability to regulate areas outside of city limits ("donut"). Rural residents felt that they were not represented in the city because they could not vote or hold office in the city. After the bills passed, city residents felt they had less power to regulate aquifer contamination from outside of the city of Laramie.

The urban-rural divide extended to conflicts over scientific data, since there were experts (UW faculty, engineers, and scientists from the community of local consulting firms) on both sides of the conflict.

While there were occasionally studies supported jointly by Albany County and the City of Laramie, much of the time the municipalities supported different aquifer protection studies. Laramie supported regional groundwater studies while Albany County supported projects on specific contamination sources (Hinckley and Moody, 2015; Wenck Associates, 2019).

Due to conflicts over experts and city studies, rural residents began conducting their own science projects to fill in knowledge gaps and to more directly address their concerns (Rovani, 2012; Starkey, 2017). Resident science had credibility among private well owners because it was created by experts and stakeholders they trusted (honest brokers) and because its conclusions aligned with their existing knowledge and experience.

City of Laramie residents and experts (who were city residents) were distrustful of resident science since it was created by people they did not trust or who they viewed as issue advocates. Resident science studies that could not be found on the internet (www.google.com search) were viewed as less credible than government studies that were available online.

As stakeholders participated in the political conflicts over the Casper Aquifer, they became more knowledgeable about the issues and more politically savvy. Stakeholder opinions of other stakeholders reinforced themselves because of the way those opinions colored further interactions. Lastly, stakeholders became fatigued by the conflict over time.

Despite the conflicts and divides, there were also many connections between stakeholders. Stakeholders lived and worked in close proximity and often interacted across the urban-rural divide. Stakeholders also had many shared values and culture.

Projects that cross this divide include the ongoing Pilot Hill Project and the Environmental Advisory Committee (EAC).

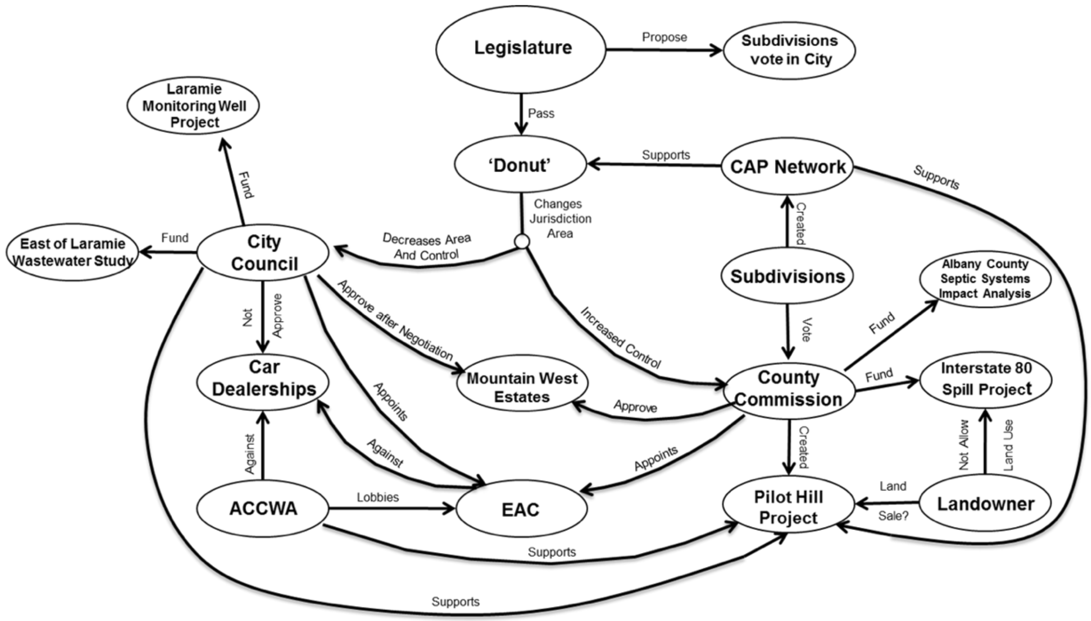


Fig. 1. Groups, Studies and Regulations Involved in Conflicts in Laramie 2013-2018

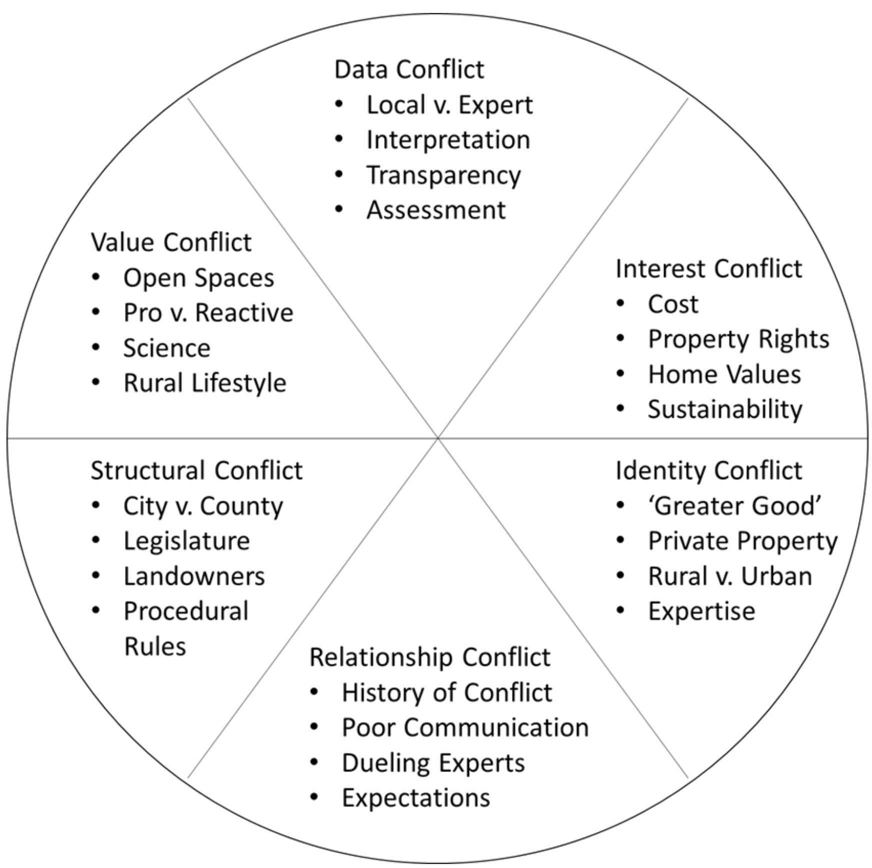


Fig.2. Circle of Conflict in Laramie 2013-2018

Table 1. Changes in Situation Maps and Circles of Conflict 1990-2018

Topic		1990	2013	2018
Situation Maps		Small-scale conflict with a small number of groups.	Height of conflict, where many groups are involved. Opposing sides, city and county.	Decrease in groups as conflict de-escalates. Many groups are less active in the conflict.
Circles of Conflict	Values	• Science • Risk • Precautionary Principle	• Open Space • Drinking Water • Science • Rural Lifestyle	• Open Space • Proactive vs. Reactive • Science • Rural Lifestyle
	Data	• Interpretation • Assessment	• Interpretation • Assessment • Lack of Data • Missing Data • Procedures	• Interpretation • Assessment • Local v. Expert • Transparency
	Interest	• Business Opposition • Competition • Procedure	• Property Rights • Home Values • Future Gens.	• Property Rights • Home Values • Sustainability • Cost
	Structural	• City v. County • Rural v. Urban • Landowners	• City v. County • Legislature • Landowners • University	• City v. County • Legislature • Landowners • Procedural Rules
	Relationship	• Dueling Experts	• Dueling Experts • Poor Communication • Emotions	• Poor Communication • Dueling Experts • History of Conflict • Expectations
	Identity	• Reputation • Recognition	• ‘Greater Good’ • Private Property • Urban vs. Rural	• ‘Greater Good’ • Private Property • Rural v. Urban • Expertise

Explanation: Table 1 is a condensed form of multiple situation maps and circles of conflict. The Situation map row under the year 2018 column is a short description of Fig. 1. The Circle of Conflict rows under the year 2018 provide the same information as in Fig. 2 but in table form instead of circle (wheel diagram) from. The information under the 1990 and 2013 columns is from Jarvis, 2014.

Policy Recommendations

The Laramie community has a high capacity for addressing the political conflict over the Casper Aquifer on their own. However, two policy recommendations are suggested based on the assessment. The first is to increase the scope of the Casper Aquifer issue by working on problems that encompass a larger geographic area or a larger issue (Wolf et al., 2010).

The second is to build coalitions between multiple groups to work together on small joint projects that address shared concerns. The projects could then be leveraged to build trust and motivate joint endeavors on larger projects (O'Brien, 2012). There are already some joint projects, such as the Pilot Peak Project, that could be further leveraged.

References

Albany County Planner, 2011, Casper Aquifer Protection Plan: Albany County, Wyoming, 132 p.

Hinckley, B., and Moody, C., 2015, Phase II - Laramie Monitor Well Project Report: City of Laramie, 145 p., https://www.cityoflaramie.org/DocumentCenter/View/8384/Phase-II-Report-final-complete (accessed February 2019).

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

O'Brien, M., 2012, Review of collaborative Governance: Factors Crucial to the internal workings of the collaborative process: New Zealand Ministry for the Environment Publication Number CR 135.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Starkey, R., 2017, Overview of the Casper Aquifer Protection Network Groundwater Sampling Program: presented to the Albany County Board of County Commissioners and to the Albany County Planning and Zoning Commission.

Wenck Associates, 2019, Albany County Septic System Impact Analysis: Wenck Associates, Albany County, Wyoming Department of Environmental Quality, 269 p.

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

Wolf, A.T. et al., 2010, Sharing Water, Sharing Benefits; Working Towards Effective Transboundary Water Resources Management: United Nations Education, Scientific and Cultural Organization, 284 p.

6.4 Final Words

NOWTS is a wicked problem rife with interwoven science and political conflict, like so many environmental issues, but with an understanding of the local context, good communication, and trust building between competing interests, conflicts over wicked problems can continue to move forward. In the words of a Laramie City Councilor, "Things are not as good or as bad as they look. … Laramie is in pretty good shape."

6.5 References

Ansell, C., and Gash, A., 2007, Collaborative Governance in Theory and Practice: Journal of Public Administration Research and Theory, v. 18, p. 543–571.

Clark, F.A., and Illman, D.I., 2001, Dimensions of Civic Science: Science Communication, v. 23, p. 5–27.

Daniels, S.E., and Walker, G.B., 2001, Working through environmental conflict: the collaborative learning approach: Westport, CT, USA, Praeger.

EPA Code of Federal Regulations (40 CFR 141):

Greer, F.R., 2005, Infant Methemoglobinemia: The Role of Dietary Nitrate in Food and Water: PEDIATRICS, v. 116, p. 784–786, doi:10.1542/peds.2005-1497.

Heikkila, T., and Gerlak, A.K., 2005, The Formation of Large-scale Collaborative Resource Management Institutions: Clarifying the Roles of Stakeholders, Science, and Institutions: Policy Studies Journal, v. 33, p. 583–612, doi:10.1111/j.1541-0072.2005.00134.x.

Kurki, V., 2016, Negotiating Groundwater Governance: Lessons from Contentious Aquifer Recharge Projects: Tampere University of Technology, 169 p., https://tutcris.tut.fi/portal/files/6149146/Kurki_1387.pdf.

L'Hirondel, J., and L'Hirondel, J.L., 2001, The case against nitrate: a critical examination., *in* L'Hirondel, J. and L'Hirondel, J.L. eds., Nitrate and man: toxic, harmless or beneficial?, Wallingford, CABI, p. 35–68, doi:10.1079/9780851995663.0035.

O'Brien, M., 2012, Review of collaborative Governance: Factors Crucial to the internal workings of the collaborative process: New Zealand Ministry for the Environment Publication Number CR 135.

Ostrom, E., 1990, Governing the Commons: The Evolution of Institutions for Collective Action: Cambridge University Press.

Rittel, H.W.J., and Webber, M.M., 1973, Dilemmas in a General Theory of Planning: Policy Sciences, v. 4, p. 155–169.

Weber, E.P., 2013, Building Capacity for Collaborative Water Governance in Auckland: Auckland Council Water Management, 51 p.

Appendix A

Fate and Transport of Nitrate from Septic Systems:

La Pine, OR and Laramie, WY

A1. Introduction

In the communities of La Pine, OR from the 1950s to the 1970s, residential subdivisions expanded outside of city limits into rural areas (Watershed Professionals Network, 2002). The majority of rural subdivisions used wells for water and onsite wastewater treatment systems (OWTS; septic systems) to dispose of wastewater. The majority of hazardous components in wastewater are treated in OWTS or as the wastewater infiltrates through the soil to the water table (vadose zone).

Starting in the 1970s, concern over rural subdivisions grew among environmental and planning groups. One concern was that wastewater from OWTS was not treated to safe levels by the time it reached groundwater, which posed a threat to subdivision residents on private wells whose only water source was groundwater.

One of the products of the wastewater treatment process is nitrate (NO_3^-). Nitrate is a contaminant which is regulated in public wells to be below 10 mg/L under the 1974 Safe Drinking Water Act and the 1986 amendment that includes wellhead protection. Nitrate is regulated in public water because it increases the risk of methemoglobinemia in infants. It poses a minimal risk to older groups until dosages are multiple orders of magnitude higher than for infants.

Nitrates are ubiquitous in the environment with many natural waters having nitrate concentrations <3 mg/L (Madison and Brunett, 1984). Elevated concentrations of nitrate in surface waters can cause eutrophication and algal blooms. Nitrates are also found in foods, food additives, pharmaceuticals, and fertilizers (Bedient et al., 1997; L'Hirondel and L'Hirondel, 2001).

In La Pine, OR and Laramie, WY, nitrate from OWTS (NOWTS) has been an area of conflict for decades. This conflict has many sources (Appendix B). This study addresses one of the multitude of controversial scientific questions about NOWTS: how much nitrate from septic systems passes through the vadose zone and reaches groundwater in La Pine, OR?

There were many motivations for this study: (1) The Deschutes County Citizen's Action Group (CAG) wanted a third party to study NOWTS in La Pine. (2) Politics limited the type of study that could be completed in the area. (3) The study checked assumptions made by previous studies about conditions in the vadose zone that were the basis of land use regulations (Gannet and Lite, 2004; Hinkle et al., 2005; Rich, 2005; Morgan et al., 2007). (4) Nitrogen fate and transport is highly complex in the vadose zone, and stakeholders wanted a greater understanding to develop their views on NOWTS conflicts. (5) Stakeholders were interested in determining the most helpful type of scientific studies and analyses for stakeholder understanding of NOWTS.

A2. Literature Review

This section was written assuming that some readers know nothing about NOWTS. The first section follows wastewater from the house to the aquifer. The second section provides background information on the field sites in La Pine and Laramie. The third section reviews the scientific literature on NOWTS in the vadose zone. The fourth section provides background on the models used for this study.

A2.1 Wastewater Home to Aquifer

This section summarizes the main processes that occur to wastewater as it passes through a septic system. Wastewater treatment is highly complex and there are many environmental factors that can affect the conditions, as well as many competing biologically mediated processes.

In rural areas of La Pine and Laramie, the main form of onsite wastewater treatment was the conventional septic system. Conventional septic systems collect wastewater in a septic tank. In a septic tank, solids, oil, and grease are given time to separate from wastewater. The wastewater from the septic tank is distributed into the vadose zone through the leach field. After wastewater leaves the leach field, it infiltrates through the soil before reaching groundwater. In the soil near the leach field, a biomat forms as microbes consume the organic materials from wastewater, forming nitrate. The process of breaking down nitrate to nitrogen gas is slower than nitrate formation under aerobic conditions (Grady et al., 2011), which can cause nitrate to accumulate in groundwaters.

As organic matter in wastewater is decomposed in the septic tank or vadose zone, nitrogen is released in the form of ammonia (NH_3). In the biomat and vadose zone, microbes aerobically digest the ammonia, forming nitrate in a process called nitrification. Under the aerobic conditions (oxygen rich conditions from air circulating through the soil) in the vadose zone, nitrate is relatively stable, and nitrate concentrations in groundwater from natural sources are often <3 mg/L (Madison and Brunett, 1984).

Nitrate is removed from groundwater and converted to N_2 gas through the process of denitrification, which is favored in anaerobic (oxygen poor) conditions and is a slower process than nitrification (Grady et al., 2011). Denitrification is a complex process requiring many steps by many different types of organisms. Many of the denitrification steps are reversible, and environmental factors can hinder the reactions. These processes make predicting rates of denitrification difficult, since rates can change by many orders of magnitude (McLaren, 1976; Hofstra and Bouwman, 2005; Schlesinger and Bernhardt, 2013).

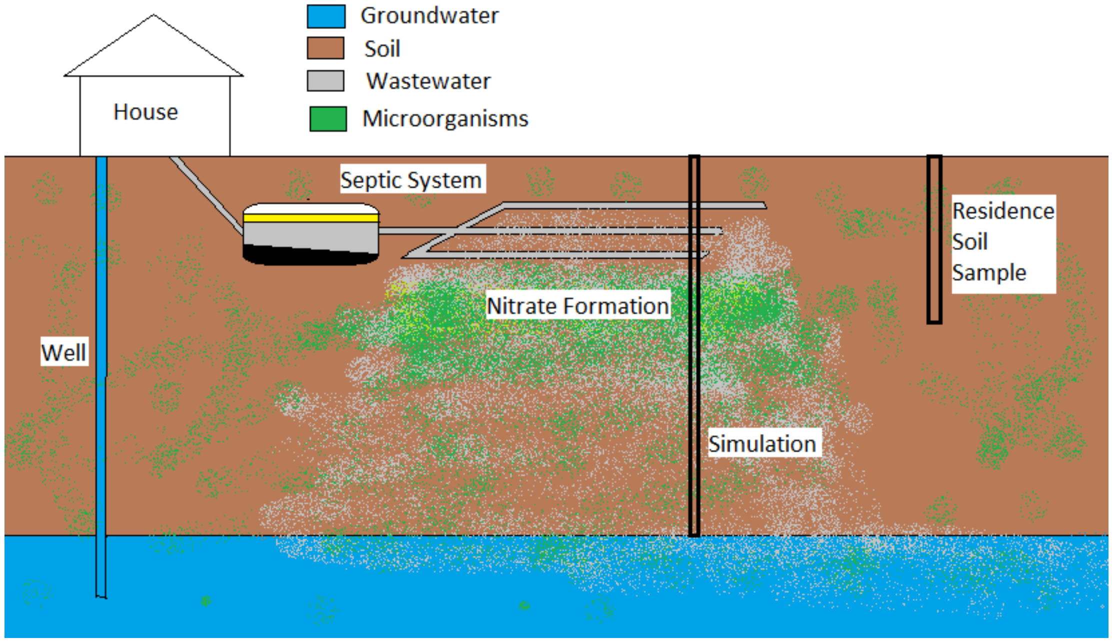


Fig. A1. Septic System Hydrology

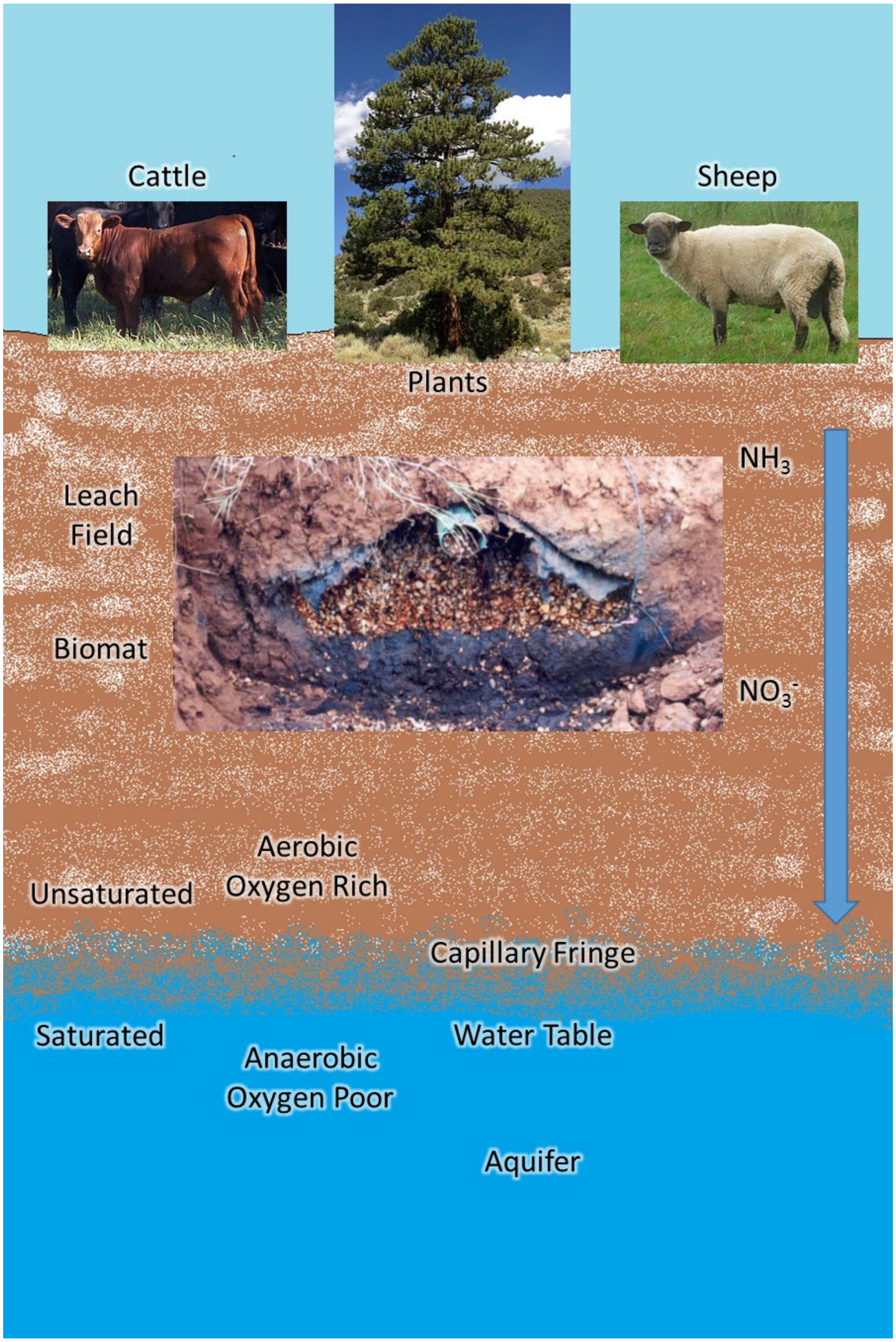


Fig. A2. Nitrogen Transport and the Subsurface
Leach Field image from (Rainwater and Jackson, 2004); other images are open source.

A2.2 La Pine

The City of La Pine is located in Central Oregon, 28 miles south of Bend, OR along the Little Deschutes River at an elevation of 4,235 ft, and is within the La Pine Subbasin. The only source of potable water for the approximately 18,000 residents of the La Pine Area is groundwater from the La Pine Subbasin Aquifer. The main source of manmade nitrate is the approximately 7,000 septic systems in the area (Rich, 2005; Cole, 2006; Morgan et al., 2007).

The La Pine Subbasin Aquifer covers an area of approximately 287 miles^2 (mi^2). The La Pine Subbasin Aquifer is in a graben that is 1,400 ft deep and has been filled with fluvial sediment derived from volcanic material (Morgan et al., 2007) and diatomaceous earth from ancient lake and marsh sediments (Fig. A5 and A6; Spurr, 2017). The sediment is heterogeneous both horizontally and vertically, with grains having varied degrees of weathering from sedimentary processes. Volcanic materials are from cinder cones in the western part of the subbasin, the Newberry Volcano on the eastern boundary of the subbasin, and Mt. Mazama (Crater Lake) which is south of the subbasin. The volcanic materials are mainly pyroclastic deposits formed by ash-flow tuff, pumice-fall tuff, and mudflows, derived from rhyolite, rhyodacite, andesite, and basaltic andesite (MacLeod and Sammel, 1982). Water was mainly produced from sand and gravel deposits occurring from 10 ft to 100 ft below the ground surface (Morgan et al., 2007)

The surface soils of the La Pine Subbasin Aquifer are described locally as pumice sand and are classified as Shanahan loamy coarse sand (Morgan et al., 2007;

USDA, 2018b). The soil environment for the La Pine Area is xeric to cyric. These soils have high permeability, poor drainage, and a water table near the ground surface (Gannett, 2001).

The climate within the subbasin is heterogeneous; the High Cascades can have >70 inches (in.) of rain a year (yr), while the City of La Pine ranges from 16 in/yr to 24 in/yr with an average rainfall of 20 in/yr. The estimated recharge for the subbasin is 2 in/yr (Morgan et al., 2007).

In the La Pine Area there is a greater risk of NOWTS contaminating groundwater than in other areas, due to the shallow water tables (averaging 20 ft) and porous soils (Gannet and Lite, 2004; Hinkle et al., 2005, 2007, 2008; Morgan et al., 2007). Concern over nitrate has grown because the population of Deschutes County grew almost 54% between 1990 and 2000, increasing rural development and septic systems, according to the US Census.

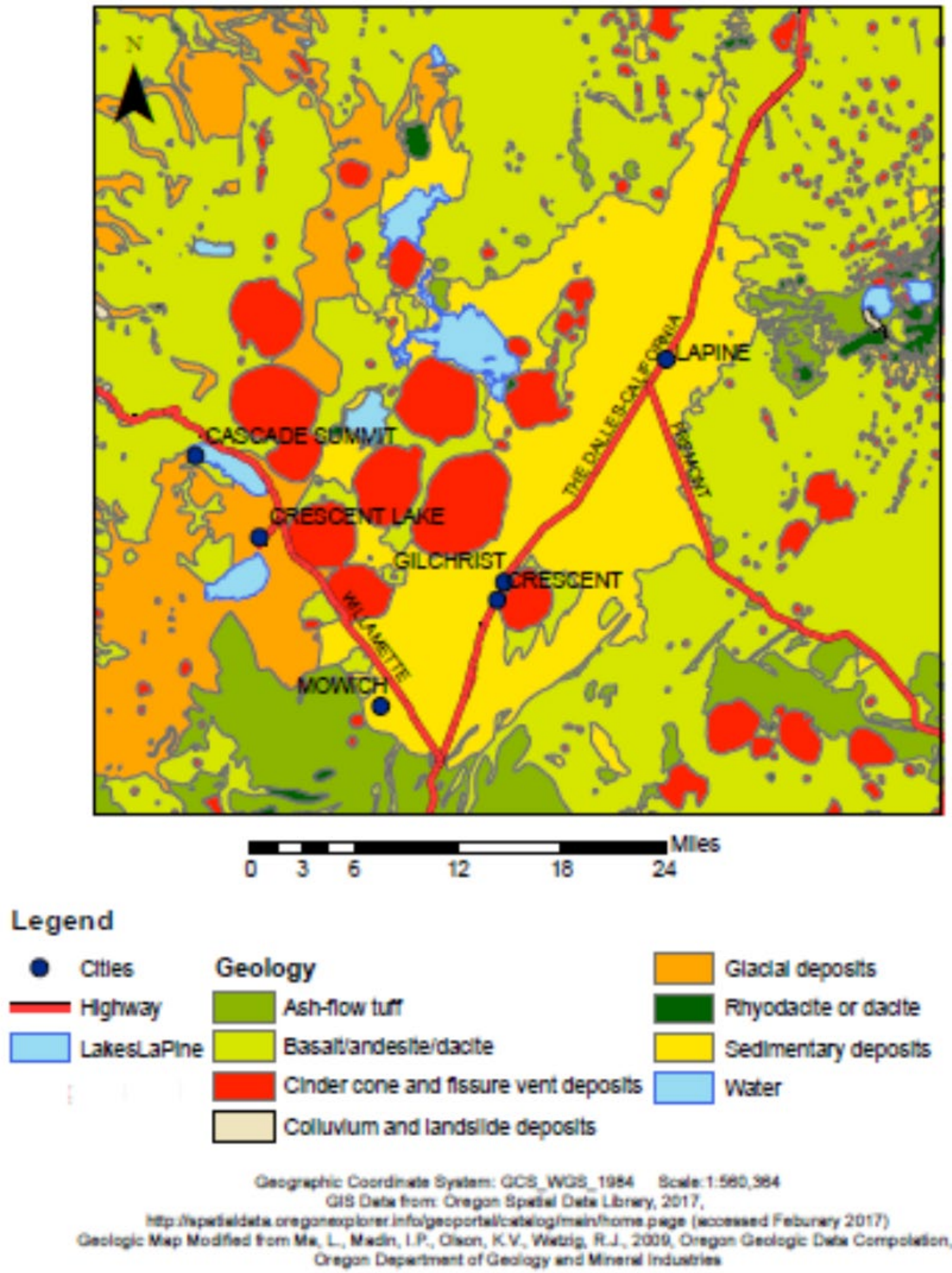


Fig. A3. Geological Map of the La Pine Subbasin

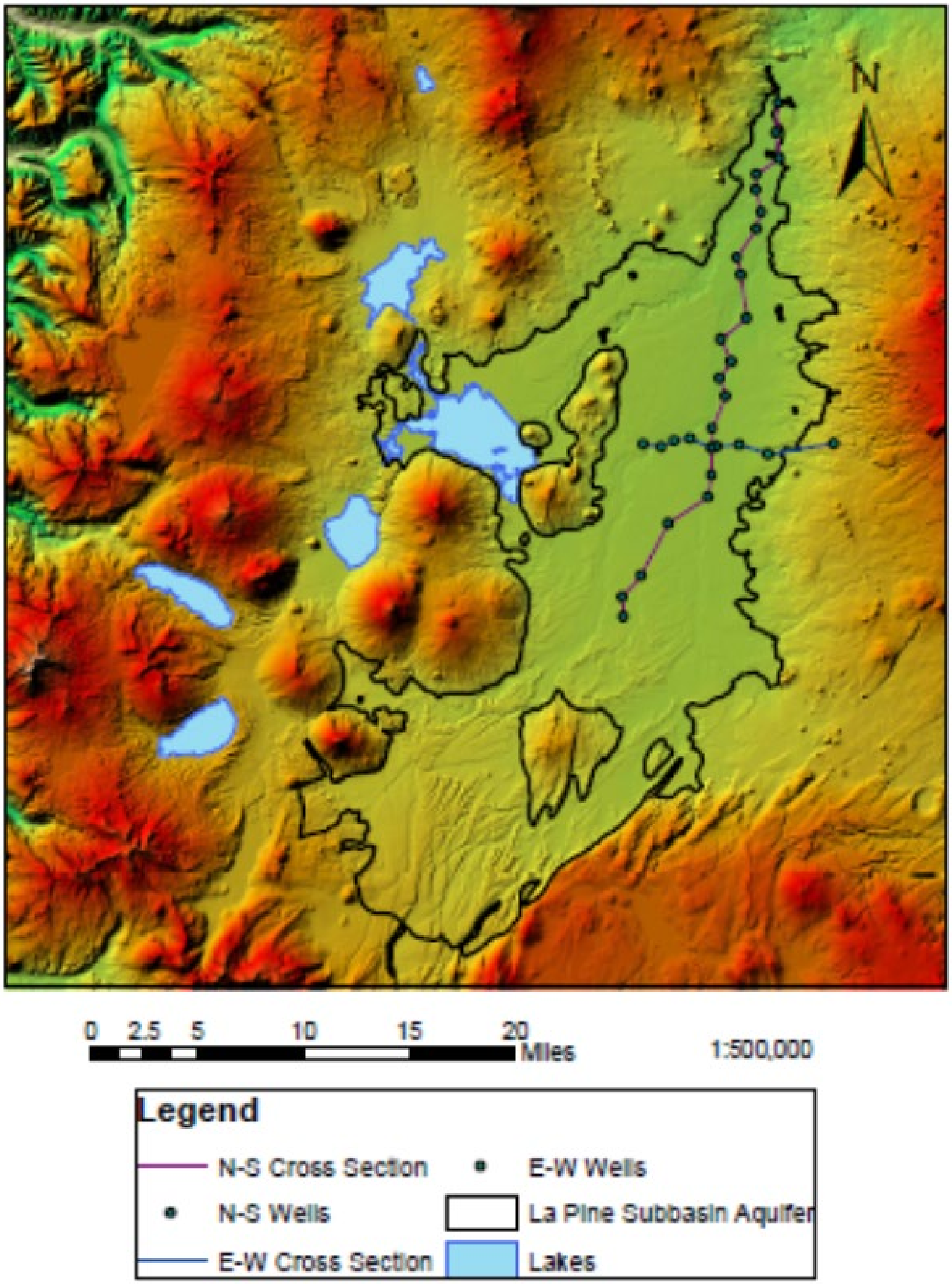


Fig. A4. Extent of La Pine Subbasin Aquifer
Based on sedimentary deposits Fig. A3

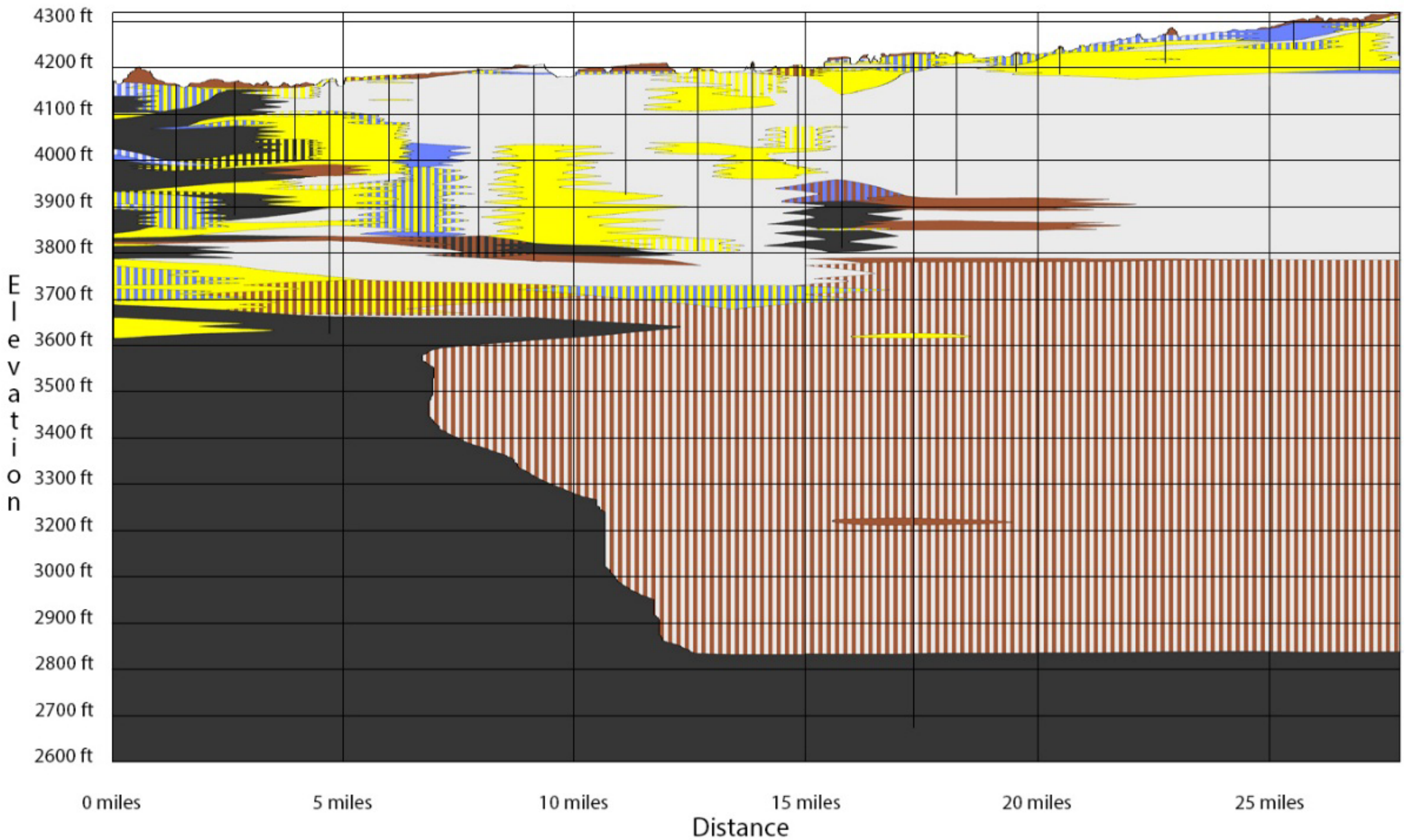


Fig. A5. North-South Cross-Sections of the La Pine Subbasin
Legend in Fig. A6

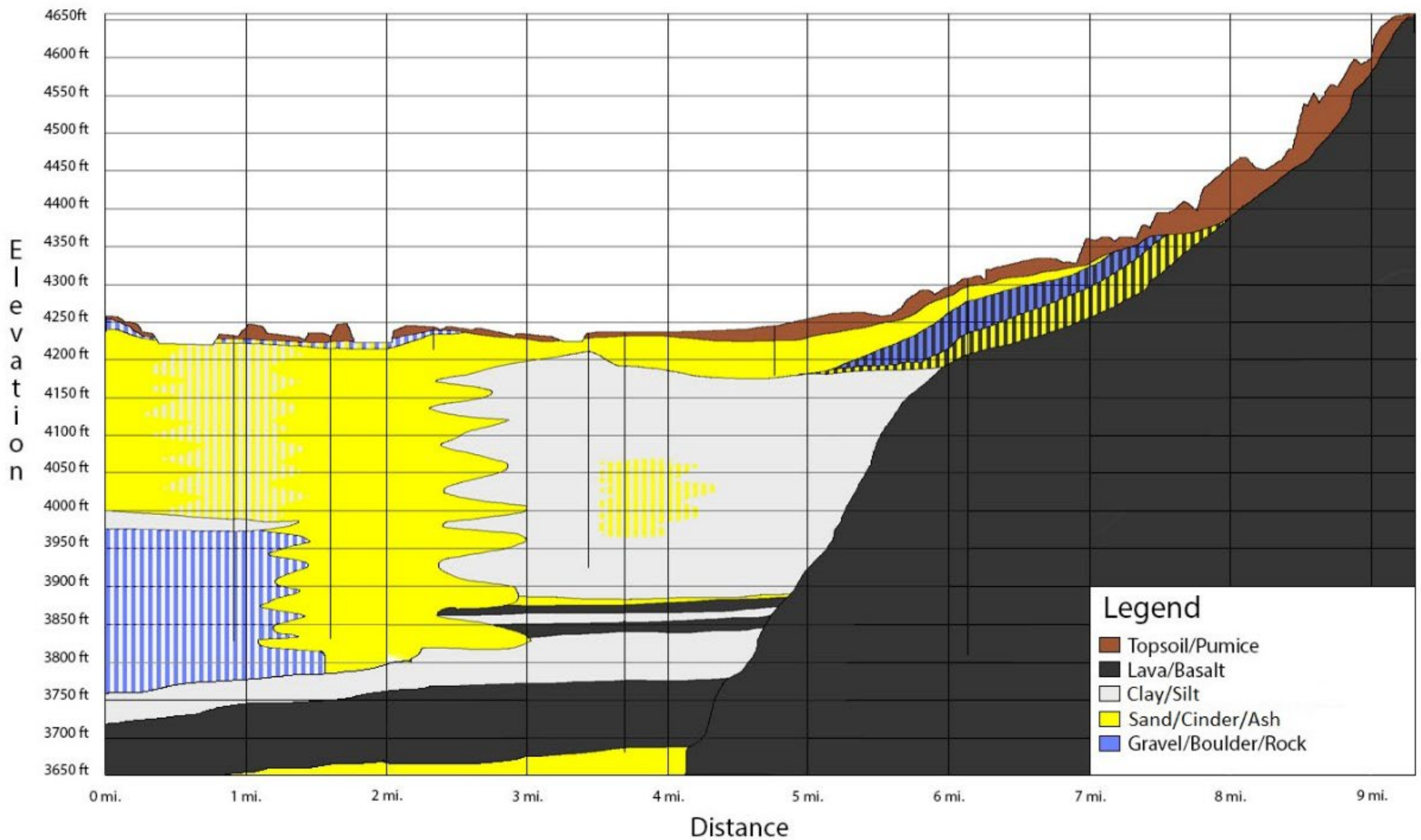


Fig. A6. East-West Cross-Section of the La Pine Subbasin
Cross-sections are based on the three deepest well logs with matching address and section in the Oregon Water Resources Department Well log database.

A2.3 Laramie, WY

The City of Laramie is located in southeastern Wyoming on the west side of the Laramie Range at an elevation of 7,165 ft. The climate of the region is semi-arid with an average rainfall of 11 inches, average high temperature of 80 °F during the summer, and average lows of 10 °F during the winter. According to the 2010 US Census, the City of Laramie had a population of 30,816. Albany County, the County in which Laramie is located, had a 2010 population of 36,299. Included in the census is the student population at the University of Wyoming (UW) of 13,657 in 2010.

The main water source for the City of Laramie is the Casper Aquifer, which provides approximately 60% of Laramie's water, with the remainder coming from the Laramie River. The City of Laramie provides water for 95% of the residents in Albany County. The Casper Aquifer is the only source of water for residents of subdivisions to the east of Laramie (WHPA, 2008).

The City of Laramie is located in the Laramie structural basin, which is a north plunging asymmetric syncline. Laramie is on the southeastern side of the basin, and the crest of Laramie Range is approximately 5 miles east of Laramie. The Casper Aquifer is in sandstone layers in the Casper Formation. The Casper Formation is composed of 650-700 ft of interbedded sandstone and limestone (which comprise 85% and 15% of the formation, respectively) and is subdivided into five members. The Casper Formation is exposed east of Laramie and dips at 3-5 degrees westward under the City of Laramie (Wittman Hydro Planning Associates (WHPA), 2008; Albany County Planner, 2011). The limestone is relatively impermeable but has faults and karst features while the sandstone is permeable and produces water for wells.

Above the Casper Formation is the Satanka Shale, which is mainly composed of shale interbedded with siltstone and sandstone. The Satanka Shale acts as a confining layer for the Casper Aquifer. Below the Casper Formation is Sherman Granite, which is relatively impermeable but can have fractured rock groundwater flow.

The main water-producing areas for the Casper Aquifer are near the eastern city limits of Laramie, where there are a series of springs and wells that are used for public and private water supplies.

The main NOWTS conflict in Laramie was the potential for ~400 people on septic systems (WHPA, 2008) in the Casper Aquifer recharge area to contaminate groundwater used by the City of Laramie and private well owners. Stakeholders attributed nitrates in groundwater to nitrogen-fixing organisms and plants (Rovani, 2012) and historical sheep ranching.

A2.4 Previous Studies

There have been few studies of nitrate transport from OWTS in the vadose zone. Studies at eight locations were found, which provided background for this study (Table A1).

In four of the study areas, lysimeters were used to gather water samples in the vadose zone beneath leach fields (Hinkle et al., 2005; Rich, 2005; Weaver, 2014; Rayne et al., 2018; Wenck Associates, 2019). Hinkle (2005), Weaver (2014), and

Rayne (2018) placed lysimeters within 3.3 ft (1 m) of the bottom of a leach field, while Wenck (2019) placed lysimeters at depths ranging from 5-35 ft of the ground surface.

Borings and soil samples were analyzed in four of the studies (Rolston et al., 1996; Rainwater and Jackson, 2004; Izbicki et al., 2015; Wenck Associates, 2019). Rolston (1996) drilled two borings to a depth of 50 ft and measured soil nitrate concentrations with depth, in a leach field and near a storage pit. Rainwater (2004) took shallow geoprobe samples beneath test leach fields but only measured for moisture and volatile organics. Izbicki (2015) tested soil nitrate and bacteria in three borings which were 39 ft (12 m) to 535 ft (163 m) deep in residential/commercial areas without sewers; one boring was near a leach field. Wenck (2019) created a boring 35 ft from a leach field to a depth of 45 ft and measured soil nitrate concentrations.

Vadose zone modeling is rare and has only been conducted at two of the sites (Carsel, 1996; Izbicki et al., 2015).

Table A1. Vadose Zone NOWTS Studies

(Rolston et al., 1996)	Davis, CA boring drilled between 2 leach field lines 25 ft apart and Salinas, CA next to a storage pit. Davis nitrate 10 mg/L near ground surface increases 20 mg/L at depth of 30-50 ft. Salinas nitrate 10 mg/L near ground surface decreases quickly to 0, remains low to depth of 50 ft.
(Carsel, 1996)	Vadose zone nitrate modeled using PRZM-2 and VADOFT, AGCHEM based on conditions in Colorado. Found nitrate 20-30 mg/L groundwater beneath septic systems. In model, 2% of nitrogen from septic reached groundwater, 59% stored in soil, the rest other processes, mainly denitrification 32%. Longer models would have less soil storage and more nitrogen leaching.
(Rainwater and Jackson, 2004)	Tested ET and ETA systems in Texas. A geoprobe took soil samples beneath and near septic moisture and volatile organics. Vadose zone not saturated <0.2 water content by weight. Excavated trench.
La Pine National Demonstration Project (Hinkle et al., 2005; Rich, 2005)	13 different systems and ATT were tested to be approved for use in the La Pine Area. The effluent in ATT was tested within the ATT system, treatment unit discharge pipe; a lysimeter was placed below leach field biomat and monitoring wells down gradient of septic systems. Septic Tank Total N 71-99 mg/L, nitrate 0 mg/L, Cl 27-96 Lysimeter nitrate 32.7-67.2 mg/L, Cl 25-85 mg/L Monitoring Well nitrate 7.0-4.3 mg/L, Cl 5.2-16 mg/L
(Weaver, 2014)	Ontario, Canada. Lysimeters were placed under 3 leach fields at distances between 33 cm and 85 cm beneath a leach field. Tested for nitrate nitrite, bromide, bacteria. Nitrate concentrations ranged from 0 to 60 mg/L beneath leach fields with leach fields following different trends at each sampling site.
(Izbicki et al., 2015)	Yucca Valley, CA, 9 borings taken in undeveloped, commercial, residential, golf course and irrigated with dairy water. Drill depth 12-163 m soil and water nitrate, Cl and isotope measurements were taken. TOUGH-2 used to model nitrate. At residential site, nitrate peaked 37-60 mg/kg at depth of 28 ft with relatively low concentrations elsewhere. Modeling 45 years for septic water to reach groundwater.
(Rayne et al., 2018)	Subdivision south of Madison, WI. 12-year study of groundwater beneath subdivisions. Monitoring wells and 2 lysimeters were placed beneath mound septic systems. Tested for nitrate, Cl, PCP, artificial sweeteners, and pesticides. Nitrate concentrations in groundwater decreased, and groundwater nitrogen transport was modeled.
(Wenck Associates, 2019)	One septic system was analyzed in subdivision near Laramie, WY. Lysimeters 5 ft - 35 ft beneath septic system, and vadose zone soil in boring near leach field. Septic tank – nitrate ND, ammonia 70.9-94.4 mg/L, TN 80-89 mg/L, Cl 30-40 mg/L. Lysimeter 5 ft TN 61-20 mg/L, nitrate 49.2-0.11 mg/L. Lysimeter 12 ft TN 0-7 mg/L nitrate 69-91.8 mg/L. Lysimeter 35 ft TN 0-2 mg/L nitrate 51-55.9 mg/L.

A2.5 Modeling

There are a variety of vadose zone transport models. The EPA maintains a catalog of over 100 models (van der Heijde, 1994). For this dissertation, two models were used to model conditions in the La Pine Area: the USDA Soil and Water Assessment Tool (SWAT) and HYDRUS 1D.

The HYDRUS simulations were created to give stakeholders a better idea of how the hydrology and contaminant transport in the vadose zone. Another goal was to try and bridge the technical/scientific view of hydrology beneath a leach field with local knowledge.

The SWAT model is a watershed scale model and the objective of using this model was to simulate the watershed-scale impacts of nitrate, using a different model than was used in (Morgan et al., 2007). The SWAT model was also used to simulate the water and nitrogen cycles for the La Pine Subbasin Watershed.

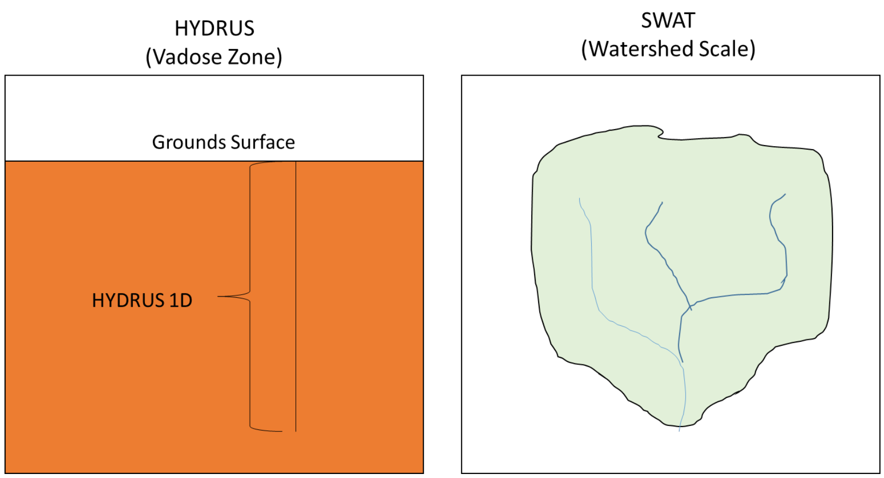


Fig. A7. Representation of HYDRUS and SWAT

A2.5.1 HYDRUS

HYDRUS is a variably saturated hydraulic model which has been developed since 1994. The model uses the Richards equation to model unsaturated hydraulic flow. HYDRUS can also model heat flow, vapor transport, solute transport, and root uptake. Solute transport also includes adsorption, root uptake, and reaction kinetics of solids for equilibrium, composition, and decomposition of solutes in 0, 1st and 2nd order reactions (Panagopoulos et al., 2007).

HYDRUS 1D was used for this study because it was free and publicly accessible, so stakeholders could check the model or create their own models. Though the goal was for stakeholders to be able to repeat the modeling, stakeholders may have some difficulties because there were few default values when setting up simulations and small changes in variables can create instabilities in the model. There are a wide variety of resources to use including the manual, journal articles, forums, and online help (Hanson et al., 2006).

A2.5.2.SWAT

The SWAT model has been used to model nitrate concentrations in ground and surface water (Panagopoulos et al., 2007). The model was developed from the Simulator for Water Resources in Rural Basins (SWRRB) model during the early 1990s. SWAT is derived from a combination of other hydrologic models (Winchell et al., 2013).

The SWAT model is a spatial model that creates simulations using a mixture of geographic information system (GIS) data and data from text in the form of databases. SWAT is a robust model that can create simulations with few inputs by using default values that are part of the model.

SWAT was chosen for this project because it was one of the few hydraulic models with the ability to model groundwater quality and OWTS. It has been used to model groundwater nitrate conditions analogous to those found in La Pine, OR (Panagopoulos et al., 2007).

The SWAT model was also used because it was an open source model and all software and data used to create the simulations were available to the public. Open source software was used so that stakeholders could replicate the simulations or create their own.

A3. Methods

Four different methods were used to determine how much nitrate from septic systems passes though the vadose zone: (1) collection and analysis of soil samples from the Pinecrest/Holmes Acres Subdivision and surrounding areas, (2) a HYDRUS simulation of the vadose zone beneath a septic systems in La Pine and Laramie, (3) analysis of public records of nitrate samples collected during real estate transactions, and (4) a SWAT simulation of the La Pine Subbasin Watershed.

Funding and in-kind services for this project were provided by Central Oregon LandWatch, CAG, and the CAP Network.

A3.1 Field Site

The field site for this study was the Pinecrest Subdivision, a mile north of the city of La Pine along Highway 97. The subdivision was composed of 91 tax lots (Deschutes County, 2009), 80 of which had been developed. The subdivision is surrounded by ranches to the north and east, and by Bureau of Land Management (BLM) land on the remaining sides.

The Pinecrest Subdivision was chosen as the sample site because:

- The subdivision was in an area that was not politically controversial.
- The subdivision was outside of city limits.
- CAG members who resided in the Pinecrest Subdivision allowed sampling to occur on their property.
- The land surrounding the Pinecrest Subdivision was owned by the BLM, which also allowed for casual sampling using a hand auger.

The sampling sites were selected to determine whether there were differences in soil properties and residual nitrate inside and outside of the Pinecrest Subdivision. One sampling site was on residential property (RES) within the subdivision. Sampling sites north (NPC) and west (WPC) of the subdivision were placed to be down gradient of the subdivision. The south sampling site (SPC) was placed between the City of La Pine and the Pinecrest Subdivision. SPC was used as a background sample for the subdivision and to determine whether there was nitrate contamination emanating from the City of La Pine.

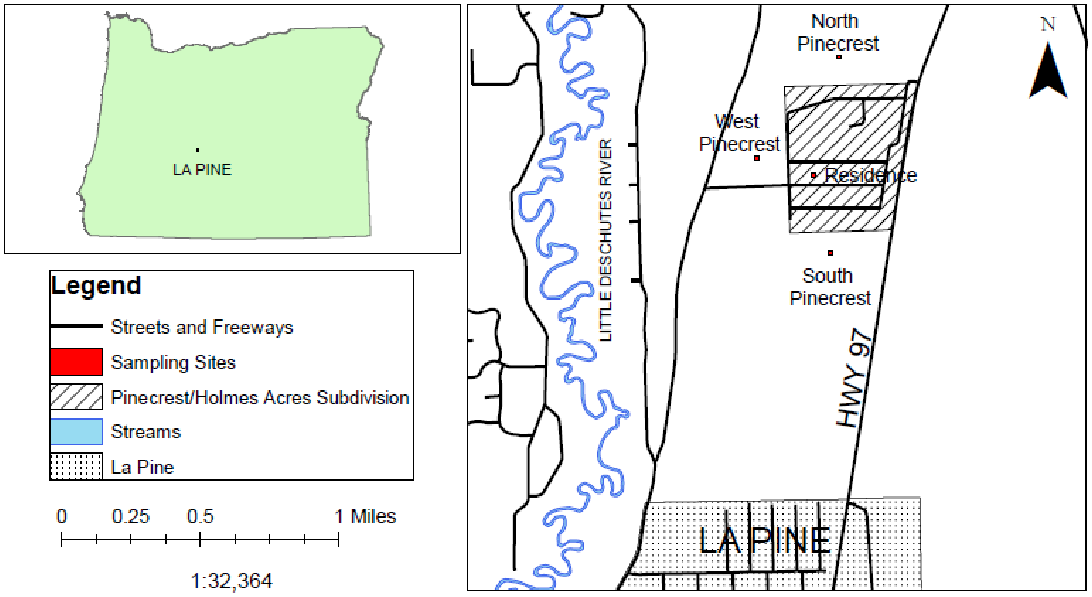


Fig. A8. Map of Sampling Locations

Table A2. Sampling Locations

Sampling Locations			
Site Name	Description	Latitude	Longitude
NPC	North of Pinecrest Subdivision	43°43'54.54"N	121°28'28.11"W
WPC	West of Pinecrest Subdivision	43°44'8.78"N	121°28'38.27"W
SPC	South of Pinecrest Subdivision	43°44'24.02"N	121°28'28.44"W
RES	Residence within Pinecrest Subdivision	43°44'5.43"N	121°28'29.90"W

Datum WGS84

A3.2 Soil Analysis

Soil sampling was conducted using a hand auger at the following locations and days: South Pinecrest (SPC) on 10/15/2017, Residence (RES) on 10/24/2017, North Pinecrest (NPC) 10/27/2017, and West Pinecrest (WPC) on 10/29/2017. An infiltration test was run at each site. In the field, soils were tested for pH and nitrate/nitrite using test strips.

Five representative samples at distributed depths were taken from each field site. Samples were chosen from roughly equal distances apart or if they were representative of a soil horizon. Soil samples were analyzed for pH, moisture, electrical conductivity, nitrate, ammonia, organic matter, total nitrogen, and texture. All samples were processed in the Crop and Soil Science Central Analytical Lab at Oregon State University (OSU), the earliest workday after samples were collected in the field (OSU CAL, 2017).

A3.3 HYDRUS

The HYDRUS model was used to simulate vadose zone conditions in La Pine and Laramie.

A3.3.1 HYDRUS Model Set Up

The first simulation was created to verify that infiltration rates through the soil were accurately modeled and had realistic results. The following variables were used to create the basic model, which was based on conditions in La Pine.

The depth of the soil column modeled was 20 ft (610 cm). The length of the soil column was based on well logs of the field site maintained by the Oregon Water Resource Department (OWRD). According to the well logs, the water table ranged in depth from 13-45 ft with an average depth to water of 22 ft. The average well depth in previous models used by USGS was also 20 ft (Morgan et al., 2007).

The time unit was day, because flow was relatively slow and the column was large at 20 ft (610 cm). The initial time was 0 and the final time was 150 days, which was chosen because the model would collapse after 150 time intervals due to a convergence error. To make the model more stable for longer time periods, the initial time step was set to $1*10^{-9}$ day, the minimum time step was set to $1*10^{-11}$ day, the maximum time step was set to 0.01 day, the number of iterations was increased to 10, the upper step multiplication factor was decreased to 0.7, and tolerances were increased to 0.01 water content tolerance and 0.39 in. (1 cm) pressure head tolerance. In HYDRUS 1D, the "single porosity van Genuchten-Mualem model" was used to model flow since the system did not reach full saturation.

Three materials in the soil column were sandy loam, loamy sand, and sand, which were the main materials found at the RES site. The materials were ordered from top of soil column to bottom of soil column: sandy loam (5 ft, 152 cm), loamy sand (5 ft, 152 cm), and sand (10 ft, 306 cm). This ordering was used so that each media could be differentiated when checking for model accuracy.

The default values of saturated hydraulic conductivity (Ksat) for each of the materials (sandy loam 42 ft/day (106.1 cm/day), loamy sand 4.5 ft/day (350.2 cm/day), and sand 23.4 ft/day (712.8 cm/day)) were used since default values were within the range of vertical hydraulic conductivity measured using well tests. The vertical hydraulic conductivity ranged from 0.15 ft/day (4.6 cm/day) to 2500 ft/day (13720 cm/day) with a mean of 18 ft/day (548.64 cm/day). The mean horizontal hydraulic conductivity was 60 ft/d (1830 cm/day) (Morgan et al., 2007).

The top boundary condition for the soil column for the Flow Check and Weather Check was set to "Atmospheric BC with Surface Layer," since water in the leach field can pool on the surface.

A max h at the ground surface of 10 cm was used since most water infiltrated with little runoff. The lower boundary condition was set to “Constant Pressure Head” of 0 to represent the water table. Initial pressure heads were assumed to be increasingly negative the further away they were from the water table, with 0 at the water table and -610 cm at the ground surface.

The flow of water at the top of the soil column was based on the average effluent flow from septic tanks to leach fields (45 gallon/person/day; 170 L/person/d) in the La Pine Area (Rich, 2005). In the 2010 US Census, there were 2.55 people/household (Morgan et al., 2007).

$$170\,\frac{\frac{\text{L}}{\text{person}}}{\text{d}} \times 2.55\,\frac{\text{people}}{\text{household}} = 433\ \text{L/day} = 158045\ L/year/household$$

According to (ODEQ, 2018a), leach field areas range from 450-900 ft^2; thus, the median number of 675 ft^2 (62.7 m^2) was used for this model. By combining household flow with leach field area, the flow can be converted to vertical flow:

$$\frac{158\ m^3/household/year}{62.7\ m^2} = 2.52\,\frac{m}{year}\,of\ flow = 8.26\ \frac{ft}{year}$$

$$\frac{252\,\frac{cm}{yr}}{\left(365\,\frac{day}{yr}\right)} = 0.69\,\frac{cm}{day} = 0.27\,\frac{inch}{day}$$

This calculation assumes that there is no horizontal dispersion of water in the soil and that the leach field distributes wastewater evenly.

The flows were verified by creating a flux vs time graph (Fig. A9) representing the movement of the wetting front. At positions and times on the graph with flows of - 0.708 cm/day (- 0.278 inch/day), there is a predicted net downward flux of 0.708 cm/day (0.278 inch/day), which is the maximum predicted flow. The change in flux of the 0 cm and 98 cm (3.2 ft) depths had took the longest time because water was flowing through sandy loam, the material with the finest grain size and with small pore size and hydraulic conductivity. The change in flux at depths of 403 cm (13.2 ft) to 610 cm (20 ft) are closer together because flows were faster due to large pore sizes.

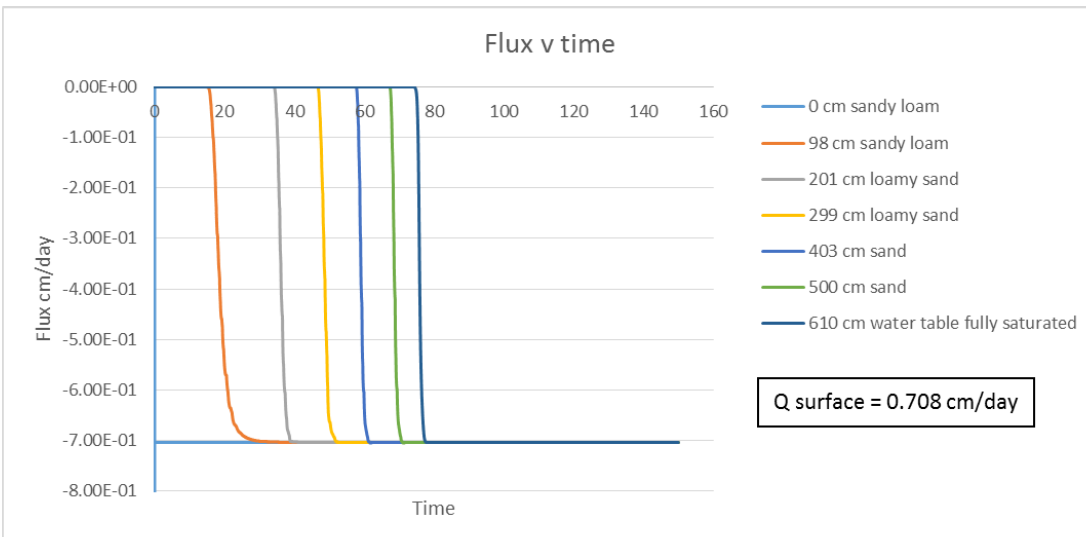


Fig. A9. Flux vs Time and Depth

The data from the HYDRUS model were checked based on flow velocities calculated from the flux graph (Fig. A9) using the following equation:

$$velocity\ graph\ = \frac{\Delta Position\ of\ wetting\ front}{\Delta Time}$$

ΔPosition of wetting front was based on the time at which maximum flux was reached at each point, and ΔTime was the number of days it took between depths reaching maximum flux.

The minimum velocity was measured based on the equation:

$$\frac{Flow\ in}{\Delta Moisture} = Velocity\ \theta$$

Where Flow in is the flow at the top of the column 0.708 cm/day, and ΔMoisture is the change in moisture from the residual moisture content to the maximum water content reach for each media. This assumes that water only flows under fully saturated conditions.

The last way that velocity was calculated was based on Darcy's Law:

$$v = K\frac{dh}{dl}$$

K is the saturated hydraulic conductivity, dh is the change in head, and dl is the length over which the change in head occurs. The Darcy velocity was the highest velocity, since it is based on saturated hydraulic flow, and velocities are much lower than K because the pores are never fully saturated.

The velocities from Table A3 are within the maximum and minimum range of velocities for flow through the vadose zone; thus, the results are reasonable.

Table A3. Comparison of HYDRUS Velocities with Darcy Velocity and Saturated Velocity

Media	K (cm/day)	Model Velocity (cm/day)	Model Velocity (Inch/day)	Saturated Velocity (cm/day)	Darcy velocity (cm/day)
Sandy Loam	106.1	4.25	1.67	2.05	5.57
Loamy Sand	350.2	7.41	2.92	2.01	12.06
Sand	712.8	9.76	3.84	1.84	21.03

The velocity was used to calculate the dispersion coefficient for nitrate using the following system of equations:

$$K\left(\frac{\mu}{\rho g}\right) = \kappa$$

$$\frac{\sqrt{\kappa}}{30} = \propto_L$$

$$D = \propto_L v$$

Where K = Saturated Hydraulic Conductivity based on HYDRUS Default values for each media, μ = 0.001452 N*s/m^2 at T=6.51°C (Average Temp), ρ = 1000 kg/m^2, g= 9.8 m/s^2, κ= Intrinsic permeability, $\propto_L$ = velocity factor, and D = Dispersion.

Table A4. Variables needed to find Dispersion Coefficient

Media	K (cm/day)	κ (cm/day)	velocity (cm/day)	$\propto_L$	D
Sandy Loam	106.1	1.57*10^{-5}	4.25	1.32*10^{-4}	5.62*10^{-4}
Loamy Sand	350.2	5.19*10^{-5}	7.41	2.40*10^{-4}	1.78*10^{-3}
Sand	712.8	1.06*10^{-4}	9.76	3.43*10^{-4}	3.34*10^{-3}
Sandy Clay	2.88	4.27*10^{-7}	2.88	2.18*10^{-5}	6.27*10^{-5}

Velocity (v) was measured by making a single media model for each media and measuring the time at which the wetting front reached each depth.

$$velocity = \frac{\Delta Position\ of\ wetting\ front}{\Delta Time}$$

The velocities were also used to estimate the potential denitrification rates. It was assumed denitrification was a first order reaction and that 25% of nitrate was removed, as was assumed in previous models of La Pine (Tillotson et al., 1980; Carsel, 1996; Morgan et al., 2007; Hinkle et al., 2008). Based on these assumptions, the denitrification has a constant rate k = 0.0034 day^{-1}.

The diffusion coefficient was 0.34 in/day (1.3*10^{-5} cm/s or 0.864 cm/day) (Yeh and Wills, 1970). The bulk density was based on (USDA, 2018a); the lower end of the estimated values was used because the sands at the field site were composed of pumice, and some grains initially floated when a hygrometer test was run to determine the clay fraction in the soil.

Many models of nitrate transport have assumed that there is no adsorption of nitrate to solid surfaces Kd = 0 (Morgan et al., 2007). The values used in this model are from Kd = 0.01, ν = 1.15, β=1.2, α=0.01 (Moradzadeh et al., 2014).

A3.3.2 HYDRUS Simulation Creation Laramie

Because stakeholders in La Pine were concerned over the denitrification rates used in previous studies (Morgan et al., 2007; Hinkle et al., 2008; Huddle, 2012), denitrification rates were instead calculated by matching simulated nitrate data to observed nitrate data from a study in Laramie, WY (Wenck Associates, 2019). Generally, denitrification rates are highly variable (McLaren, 1976). Denitrification rates for bottomless sand filters in the La Pine Area ranged from 7-12% to as high as 50% (Rich, 2005), and in other studies they were ~33% (Carsel, 1996).

Two HYDRUS simulations were combined to create the model in Laramie. The first simulation was of the top 100 cm (3.3 ft) of the soil column, and the second simulation used the results from the first simulation to simulate the rest of the 46.5 ft (1420 cm) soil column.

The two simulations were created separately and then combined because water fluxes can only be placed at the top and bottom of the soil column of HYDRUS 1D, whereas septic systems release water at a depth of ~3 ft.

The two simulations were also differentiated by the factors calculated in each simulation. The main factors calculated in the upper 3 ft simulation were evaporation and transpiration. The upper 3 ft simulation was set up so that the water table was at a depth of 3 ft and the only other inputs of water were from precipitation. The precipitation, evaporation, and transpiration were used to adjust the flow rates from the septic system in the 46.5 ft simulation. Besides inputs from the 3 ft simulation, it was assumed that there was no evaporation or transpiration in the 46.5 ft simulation. This assumes roots are not in leach fields, because they can clog the system. It was also assumed that the highest possible evapotranspiration occurred when the water table was at leach field depths and that it would be lower at deeper depths.

A3.3.2.1 HYDRUS Simulation Laramie Surface to Leach Field

For the simulation of the hydrology of the top 3 ft of the soil column, the bottom boundary was at a depth of 3.28 ft (100 cm) and was set to have a constant pressure head of zero (0) to represent a water table. The upper boundary was set to "Atmospheric BC with Surface Layer" to represent the ground's surface. The bottom 1 ft (30 cm) was sand (the coarsest material in HYDRUS), to represent the gravel in the leach field. Above the gravel, the soil texture was set to sandy clay loam. The two influxes of water for this simulation were from the water table and from precipitation.

The precipitation data for the simulation was from station Laramie 3.3 ESE, WY US, and temperature, humidity, and wind data were from station Laramie

Airport, WY US (NCDC, 2019). The weather data for January 1, 2017 to December 31, 2017 was looped for 10 years.

Parameters required to simulate evapotranspiration (evaporation and transpiration) included the latitude (41.3°) and altitude (4,236 ft, or 7,400 m) of Laramie. Potential radiation was simulated because there were no records of actual radiation. Crop data were set to be constant in order to see the effects on concentration. Leaf Area Index was set to Clipped Grass. Cloudiness was set to sunshine, since cloud data could not be found and the area was relatively dry. Day length was from the US Naval Observatory (USNO, 2015).

Root uptake was modeled using "Feddes Water Uptake"; "Maximum Allowed Root Uptake" was set to 10000 mg/L because nitrate is a nutrient, meaning that nitrate uptake should occur no matter the concentration. There was no stress included, and minimum concentration for uptake was set to 0.00062 mg/L, which is the minimum concentration of nitrate assimilated under a regime where there is excess nitrogen (Amâncio and Stulen, 2004). The number of roots was set to be 1 at the top of the soil column and decreased linearly to zero at a depth of 2 ft (60 cm). This assumed that root mass was similar to soil organic matter and that the most activity would occur near the source of nutrients (top of soil column) and would decrease further away (Horton, 1958; Selker et al., 1999).

A3.3.2.2 HYDRUS Simulation Laramie Three Feet to Water Table

For the Laramie simulation from 3 ft to 46 ft deep, the upper boundary was set to "Atmospheric BC with Surface Layer" so that the influx of water and nitrate could be varied over time. The bottom boundary was set to the water table (0 pressure head) so as to keep the simulation consistent with the La Pine simulation, though the water table in Laramie is much deeper. The soil textures were based on soil data from Wenck Associates (2019) and well logs (Fig. A10).

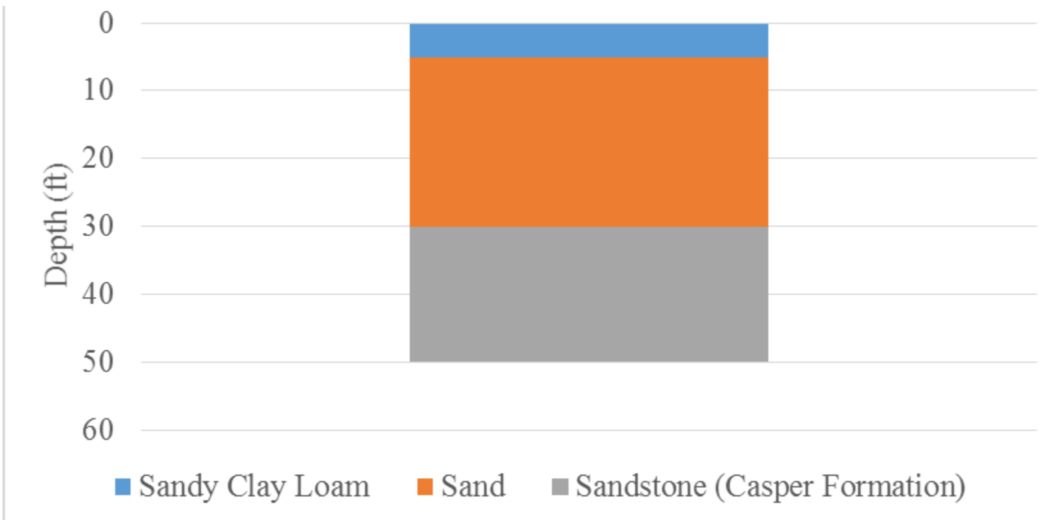


Fig. A10. Soil Column for Laramie HYDRUS Model

The solute boundary condition at the top of the soil column was "Concentration BC" and the lower boundary condition was "Zero Concentration Gradient," with the initial condition "In Liquid Phase Concentration" in units of mg.

For solute transport, default models Crank-Nicholson Scheme, Galerkin Finite Elements, and Equilibrium Model were used with one solute (NO_3). Leach fields (unless clogged) and the subsurface below leach fields tend to have aerobic conditions (Selker et al., 1999); thus, it was assumed that all N in the effluent was in the form of NO_3. This assumption was used because it is the worst case scenario for NO_3 contamination, and nitrification is fast compared to the time scale of this model (Hanson et al., 2006; Grady et al., 2011).

No weather parameters were included in the 3 to 46 ft Laramie simulation because weather was accounted for in the upper 3 ft simulation. Instead, the influx of water at the upper boundary of the simulation was calculated based on the evapotranspiration from the upper 3 ft simulation using the following formula:

$$Septic\ system\ flow + Percipitation - Evapotranspiration = Total\ Flow$$

The concentration of nitrate for water entering the system was adjusted based on the amount of water entering the system, assuming that the processes diluted or concentrated nitrate. The concentration was further modified so as to be within the range of values found by Wenck Associates 2019, and so that data better fit observed values. The denitrification rates were also adjusted so the simulation better fit observed concentrations.

Comparison and nitrate reaction parameters are in the results section.

Table A5. Laramie HYDRUS Inputs

Data	Data Used	Sources
Well Logs	Soil media and bulk density	(Wenck Associates, 2019)
Soil Type	Wycolo-Thermopolis-Rock Outcrop Complex	(USDA, 2018b)
Sandstone Hydraulic Conductivity	1.5 ft/day	(WHPA, 2008)
Column Depth	46.5 ft (1420 cm)	(Wenck Associates, 2019)
Time Period	1/1/2017 – 12/31/2017 (repeating)	
Latitude	41.3° N	
Elevation	7,400 ft	
Weather	Precipitation from Station: LARAMIE 3.3 ESE, WY US Temperature, Humidity, Wind from Station: LARAMIE AIRPORT, WY US	(NCDC, 2019)
Sunshine	Assumed hours of Daylight	(USNO, 2015)

A3.3.3 HYDRUS Simulation Creation La Pine

The same processes used to create the simulations in Laramie were used for La Pine, except that conditions were adjusted to fit conditions in La Pine. Denitrification rates from Laramie were used due to the lack of observed data to compare to La Pine.

Because there was uncertainty about the texture of the soils, two simulations were created for the La Pine area. Due to technical limitations, soil samples were only collected to a maximum depth of ~7.7 ft; thus, the deeper soil textures were determined from well logs for one simulation. Because the well logs and observed soil samples did not correlate well, a second simulation was created, extending the soil texture observed at 7.7 ft downward to cover the lower part of the soil column. The total length of the soil column was changed to 610 cm (20 ft).

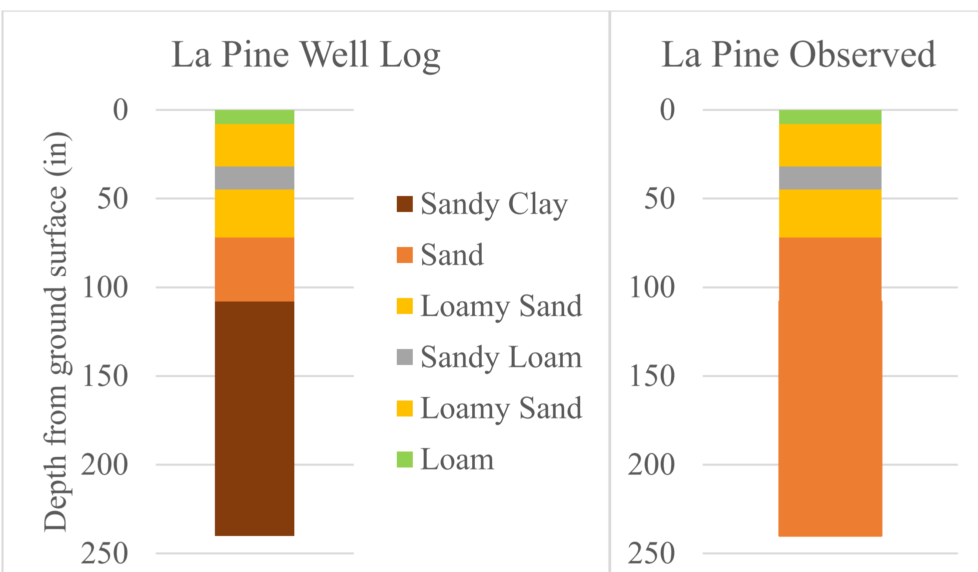


Fig. A11. Soil Column for La Pine HYDRUS Model

Weather data were mainly from the Wickiup Dam weather station (NCDC, 2019) during January 1, 2017 to December 31, 2017, which was repeated. The Wickiup Dam weather station was missing wind data for some days, which were filled in with data from the Redmond, OR Airport. The total length of the La Pine simulations was 1.5 years since this was the length of time for conditions to reach a relatively steady state in the simulations in Laramie. Shortening the time also allowed for daily weather data to be used instead of monthly weather data, to yield more detailed results.

Table A6. La Pine HYDRUS Inputs

Data	Data Used	Sources
Soil Column	20 ft (610 cm) except LW Temp Check 3ft (91 cm)	
Water Table	20 ft (610 cm) except LW Temp Check 3ft (91 cm)	OWRD Well Logs, (Morgan et al., 2007)
Time	1.5 years (1/1/2017 – 12/30/2017 repeating)	
Materials	Sandy Loam, Loamy Sand, Sand	based on soil texture at residence Section A4.1.11
Material Hydraulic Property	HYDRUS Default	
Weather Station	WICKIUP DAM, OR US (Station ID: GHCND:USC00359316) REDMOND AIRPORT, OR US Station ID GHCND:USW00024230	(NCDC, 2019)
Leach Field Flow	0.27 in/day (0.69 cm/day)	(Rich, 2005; Morgan et al., 2007; ODEQ, 2018b)
Leach Field NO_3	61 mg N/L	(Rich, 2005)
Diffusion Coefficient	0.34 in/day (0.864 cm/day)	(Yeh and Wills, 1970)
Bulk Density		(USDA, 2018a)
Dispersion	Sandy Loam - $5.62*10^{-4}$	Calculated
	Loamy Sand - $1.78*10^{-3}$	
	Sand - $3.34*10^{-3}$	
	Sandy Clay - $6.27*10^{-5}$	
Adsorption	Kd = 0.01, $\nu = 1.15$, β=1.2, α=0.01	(Moradzadeh et al., 2014)
Sunshine	Assumed hours of Daylight	(USNO, 2015)
Altitude	4,236 ft (1291 m)	
Latitude	43.6° N	
Root uptake	10,000 mg/L	
Minimum Concentration Uptake	0.00062 mg/L	(Amâncio and Stulen, 2004)
Root Depth	3.28 ft (100 cm)	(Horton, 1958; Selker et al., 1999)

A3.4 Real Estate Transaction Data

Real Estate Transaction Data for the La Pine Area was studied because it was one of the measures used by previous groups to study nitrate in the area (Morgan et al., 2007; Huddle, 2012) and was one of the few forms of recent private well monitoring for the area.

Homes were only considered if they were in area codes 97707 and 97739. Real estate transaction data were spatially mapped, graphed with time, and graphed in a histogram to show the probability distribution.

A3.5 SWAT

The SWAT model was used to create a regional hydraulic model for the La Pine Subbasin Watershed and to model water and nitrogen cycling. The SWAT model was created using the QGIS 2.6 Brighton software with the QSWAT plugin. All data used for the models were from public sources, and the projected coordinate datum used was WGS 1984 UTM Zone 10.

When the simulation was created, a 33 ft (10 m) DEM was available from the University of Oregon Library. The raster cell was changed 33 ft (10m) to 295 ft (90 m) for use in the SWAT model.

The land use data (Oregon Land Cover NLCD 2011) was from the Oregon Geospatial Library. Land use data was categorized in SWAT based on the "Global Landuses" land use table. Soil data were from the USDA-NRCS Data gateway and soil was categorized in SWAT based on the "SSURGO/STATSGO2" soil data table.

Discharge data for the watershed as well as for the reservoirs in the La Pine Subbasin were from the US Bureau of Reclamation (USBR, 2017).

In QSWAT, streams were created based on a 62 mi^2 (100 km^2) threshold. This threshold was chosen so that there would be a reasonable number (21) of sub-watersheds created by the model. The outlet for the watershed was based on the location of Benham Falls. The four smallest watersheds were combined with neighboring watersheds.

Hydraulic Response Units (HRUs) are areas within the same sub-watershed with the same land use, soil, and slope. Slope bands were created based on areas with slopes that had a grade of less than or greater than 10%. Small HRUs are often removed because their impact tends to be limited. Given that this study's interest was in subdivisions, and subdivisions cover a small percentage of the area in the La Pine Watershed, all HRUs were kept.

The La Pine Area has low density development which was categorized in the original land use map as shrub, grass, and evergreen forest. The SWAT land uses list combines Urban Low Development with Urban Medium Development, and the only developed land use areas near the watershed were in Bend, OR. To differentiate developed areas from surroundings, the land use map was changed so that areas which had subdivisions or were within city limits were mapped as crop woodland. Crop woodland was used because there were no crop woodland areas near subdivisions in the watershed.

Weather data for the model was simulated based on the WGEN_US_COOP_1990_2006 statistical database, which came with the SWAT software.

The Crane Prairie, Crescent Lake, and Wickiup Reservoirs were included in the model by placing reservoirs in appropriate sub-watersheds. Because the reservoirs are larger than can be modeled in SWAT, maximum values were used, and extra capacity from Wickiup Reservoir was added to a watershed upstream of Wickiup which contained no reservoir.

Table A7. Reservoir Characteristics

	Surface Area (ha)	Surface Area (mi^2)	Vol. (10^4 m^3)	Vol (10^6 ft^3)	Year Created
Crane Prairie	1987	7.67	6821	2409	1940
Wickiup	4102	15.8	24670	8712	1949
Crescent	1621	6.26	69890	24681	1956

Table A8. Reservoir Average Monthly Flows (m^3/s or cms) or (*35.3 ft^3/s or cfs)

	Crane Prairie			Wickiup			Crescent		
	average	min	max	Average	min	max	average	min	max
Jan	128.5	120	140	129.0	120	140	12.7	10	15
Feb	95.0	90	100	124.5	120	140	15.4	10	20
Mar	88.2	80	100	116.4	110	130	16.4	10	20
Apr	100.5	100	120	489.6	450	500	20.8	15	25
May	193.6	180	200	922.3	900	950	23.7	20	25
Jun	228.7	210	250	1115.5	1000	1150	37.1	35	40
Jul	257.4	250	300	1247.3	1200	1300	89.2	80	90
Aug	226.2	220	250	1200.0	1150	1250	126.8	120	130
Sep	184.3	180	200	936.0	900	950	78.5	70	90
Oct	157.2	150	200	329.2	300	350	6.4	5	10
Nov	110.5	100	150	61.7	55	70	5.2	5	10
Dec	97.3	90	100	64.2	60	70	5.5	5	10

Septic systems were mapped based on tax lot maps, aerial photography, and development permits from Deschutes County (Fig. A12). When mapping septic systems, it was assumed that (1) tax lots with septic permits but no buildings in aerial photos had no septic system and (2) tax lots with buildings but no septic permit did have a septic system. Both conditions were rare in the La Pine Area.

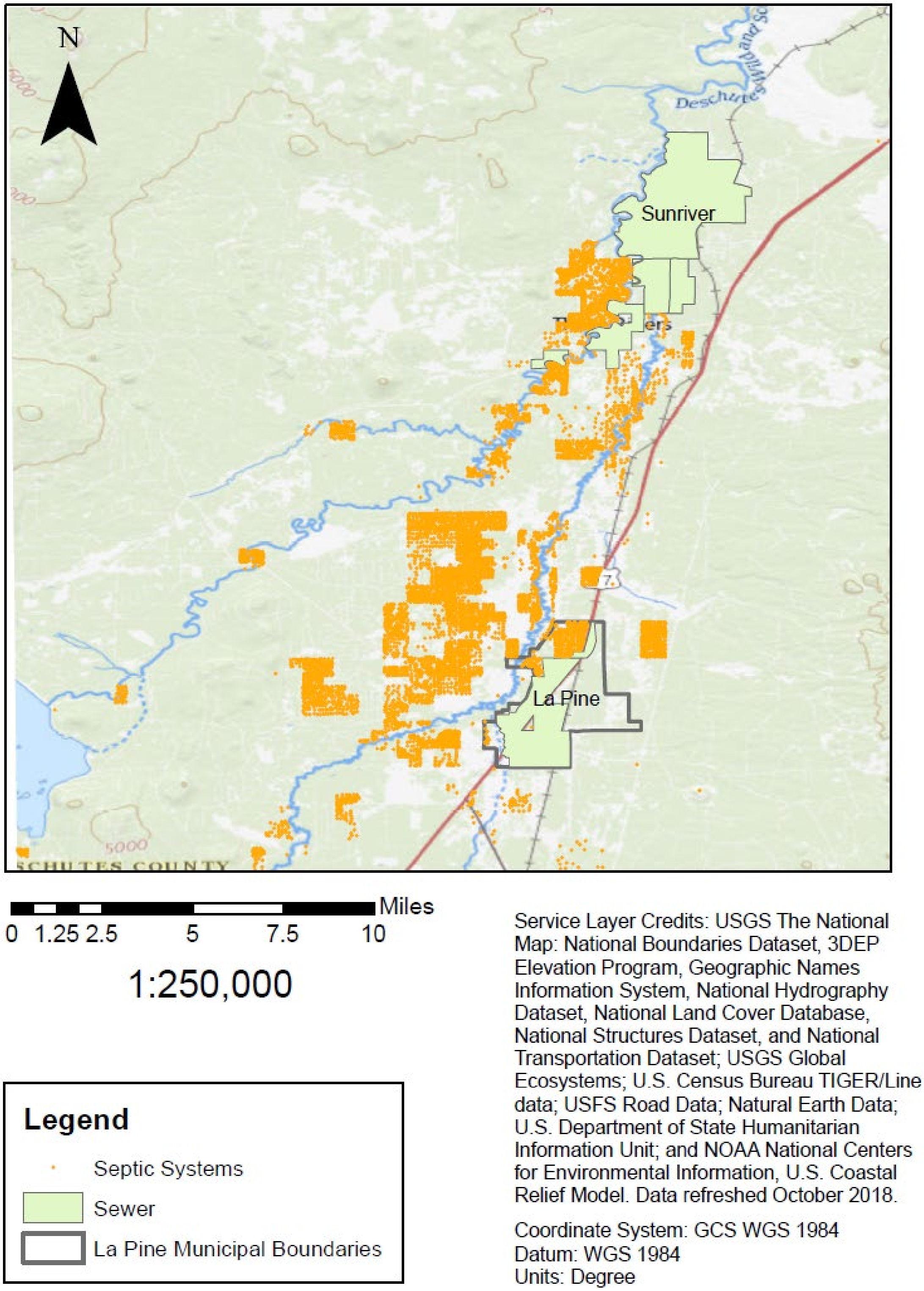


Fig. A12. Septic Systems and Sewers in the La Pine Area

Septic systems were included in the SWAT model by editing the .sep database. The following modifications were made to the .sep database to each HRU that contained septic systems: (1) Septic Operation = 1 so OWTS were in operation in the simulation. All OWTS were assumed to be conventional septic systems since conventional septic were the most common type of OWTS in the La Pine Area, though there were an increasing number of OWTS that treated for nitrate. (2) Septic Density was based on the area of HRUs and the number of septic systems within HRUs. (3) It was assumed that septic systems that were clustered outside of a "crop woodland" land use area were part of nearby "crop woodland" land use areas. (4) Septic systems were not added to HRUs with a small number of highly dispersed septic systems.

Negligible atmospheric deposition of nitrate was assumed in the La Pine Area. The two potential sources of atmospheric deposition of nitrate in the La Pine Area are the combustion of fossil fuels and ocean spray. These sources of atmospheric nitrate are at low density or are distant from the La Pine Area, respectively (Schlesinger and Bernhardt, 2013).

The model simulated a time period between 1/1/2000 and 1/1/2005. Different scenarios were created, including doubling and quadrupling the density of septic systems and testing what would happen if all septic systems failed.

A4. Results

A4.1 Soil Sampling Results

A4.1.1 Field Conditions

The SPC field site was sampled with assistance of a local resident. Although it had rained at the site two days prior to sampling, conditions were warm and dry with sparse clouds and a slight breeze.

Table A9. Well Log SPC

Depth	Media Characteristics
0 - 6 in (0 - 15 cm)	dark tan/light brown silt with some pumice sand (organic rich)
6 - 11 in (15 - 28 cm)	transition to lighter white pumice sand
11 - 24 in (28 - 61 cm)	white pumice sand
24 - 33 in (61 – 83 cm)	increasing pebble/gravel size with depth
33 - 46 in (83 -117 cm)	gravelly, dark brown sand
46 – 66 in (117-168 cm)	black gravel

The RES field site was sampled with assistance of a local resident. The RES field site was the most densely wooded field site.

Table A10. Well Log RES

Depth	Media Characteristics
0 - 2 in (0 - 5 cm)	decomposing organic matter
2 - 8 in (5 - 20 cm)	light brown organic rich silty soil (the wetting front was to a depth of approximately 8 inches)
8 - 32 in (20 - 81 cm)	white pumice sand
32 - 66 in (81 – 168 cm)	increasing pebble/gravel size with depth

The NPC field site (Fig. A13) was sampled without field assistance. This area was lightly wooded and most of the trees were young with a breast height diameter less than 1 ft.

Fig. A13. Sampling Location at NPC
Photo taken 10/29/2017, facing southwest.

Table A11. Well Log NPC

Depth	Media Characteristics
0 - 8 in (0 - 20 cm)	light brown organic rich silt
8 - 27 in (20 - 69 cm)	light tan pumice sand, roots
27 - 34 in (69 - 86 cm)	silt/clay, diatoms
34 - 45 in (86 - 114 cm)	increasing pebble/gravel size with depth
45 - 92 in (114 - 233 cm)	dark colored gravel

WPC was sampled without field assistance. It was a warm, sunny day with a cool breeze. There were many old stumps near the sampling site.

Table A12. Well Log WPC

Depth	Media Characteristics
0 - 12 in (0 - 30 cm)	light brown silt, organic rich lots of roots
12 - 25 in (30 - 63 cm)	light tan pumice sand, roots
25 - 28 in (69 - 86 cm)	silt/clay
28 - 50 in (86 - 114 cm)	increasing pebble/gravel size with depth

A4.1.2 Acid/Base Chemistry

The pH of the soils was neutral near the ground surface and more alkaline/basic at depth (Fig. A14).

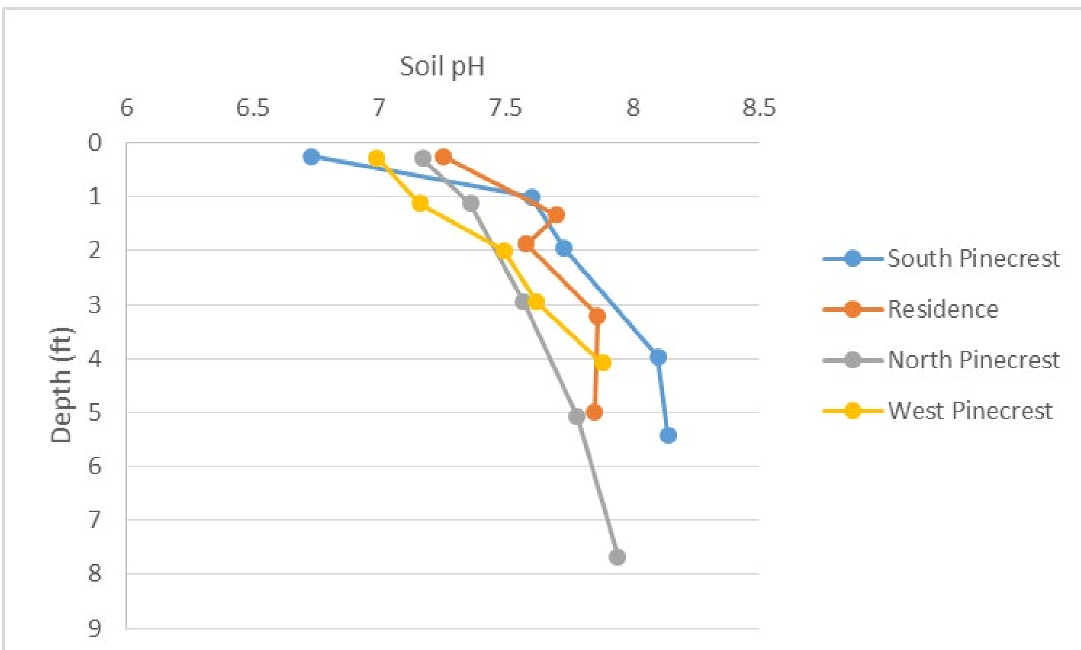


Fig. A14. pH vs. Depths in Pinecrest Subdivision

The pH of the samples increased with depth for all samples. There are many processes that could lead to this type of soil profile. At depth, the alkalinity could be attributed to the weathering of silicate and carbonate minerals. The lower pH at the ground surface could be due to precipitation, which often has a pH of 5.7 from equilibrium with carbon dioxide. Both plant growth and decomposition of organic and inorganic matter can also lower pH (Schlesinger and Bernhardt, 2013).

A4.1.3 Infiltration

Infiltration is a measure of how quickly water is able to percolate the ground surface. One of the main factors affecting infiltration is the water content of the soil. When the water content was low, infiltration was fast, and when the water content was high, the infiltration rate was slow. Run 1 at each location was considered unsaturated. Later runs were considered increasingly saturated since water from previous runs saturated the soil. The number of infiltration tests was limited by the time available at the field site.

Infiltration results in the Pinecrest Subdivision were highly variable, ranging from 39 in/hr (990 mm/hr) unsaturated infiltration rate to 3.1 in/hr (79 mm/hr) saturated infiltration rate.

Table A13. Infiltration rates in Pinecrest Subdivision

Location	Run #	Rate (in/hr)	Rate (mm/hr)
SPC	1	16.2	411
	2	5.5	140
RES	1	6.7	171
	2	3.1	79
NPC	1	35.9	911
	2	39.0	990
	3	33.1	841
	4	35.3	896
WPC	1	33.3	847
	2	26.9	684
	3	15.3	389
	4	6.7	170

The RES had the slowest infiltration rates (6.7 in/hr – 3.1 in/hr), and the samples outside of the subdivision had higher infiltration rates (39 in/hr – 5.5 in/hr). This may be due to the looseness or compaction of the soil. The surface soil within the subdivision was compact, but the surface of the soil outside the subdivision was loose with texture similar to a sandy beach.

NPC had the highest infiltration rates, caused by preferred flow pathways (pore sizes that are larger than the average pore size in surrounding soil). The soil underneath the infiltration ring was dug out, revealing that the soil on one side of the infiltration ring was saturated with water while the other side was dry (Fig. A15). Preferred flow pathways can be caused by a variety of natural processes, including roots and fauna (such as, worms) (Schlesinger and Bernhardt, 2013).

Fig. A15. Infiltration site at NPC after infiltration test

The soil also showed some hydrophobicity in some areas. When a few drops of water were placed on dry soil, the water would bead and take a few minutes before soaking into the ground. There were accounts by locals of water ponding on the ground surface after a long dry period and water infiltrating very quickly during winter months with no ponding.

A4.1.4 Field Measurements of pH and Nitrate

Although nitrate/nitrite and pH test strips provided accurate measurements, they lacked the precision required for this study. From lab analysis, the surface soil pH ranged from 6.73 -7.25 (Fig. A14), while the pH measured from the test strips ranged from 5-6 (Table A14). Because the pH of the soils was near neutral, there was little change in color between a dry pH test strip and a wet one, which made it difficult to visually determine pH.

Table A14. Field Measurements of pH, Nitrate, and Nitrite

Tests with pH and Nitrate Paper				
Location	Depth (ft)	pH	Nitrate (mg/L)	Nitrite (mg/L)
SPC	0	5	1	0
	5.5	5	1	0
RES	0	6	2	0
	1	6	2	0
	3	6	2	0
NPC	0	5	2	0
WPC	0	5	5	0

The nitrate concentrations from the ground surface samples were low (0.11 - 1.2 mg/L), at the lower range of use for the test strips, which range from 0-50 ppm. The color difference was difficult to visually assess for some samples because dirt from the soil water mixture would accumulate on the test strip, making the test strip appear darker. It was especially difficult to determine lower concentrations of nitrate, which were shades of light pink.

For this study, nitrate/nitrite test strips were highly inaccurate for measuring soil nitrate in the field. This was demonstrated by the very low concentration of nitrate found in the test strip at 3 ft at the RES sampling site, which showed only 2 mg/L, while the concentration of the lab sample was 28 mg/L, possibly due to the extraction methods used in the lab. Replicate samples were not completed because samples were weeks over the hold time by the time results were received.

Results from pH strips were relatively accurate for measurements of soil pH. Because the pH of the soils in the La Pine area is relatively neutral, there was very little change in the test strips. pH test strips and nitrate/nitrite test strips suffered the same difficulty, in that dirt particles accumulated on the test strip, making it more difficult to determine the color.

A4.1.5 Soil Moisture

Moisture content was highest near the ground surface and decreased with depth (Fig. A16). Moisture analysis was conducted on the sample from SPC, but the Central Analytical Lab lost the results.

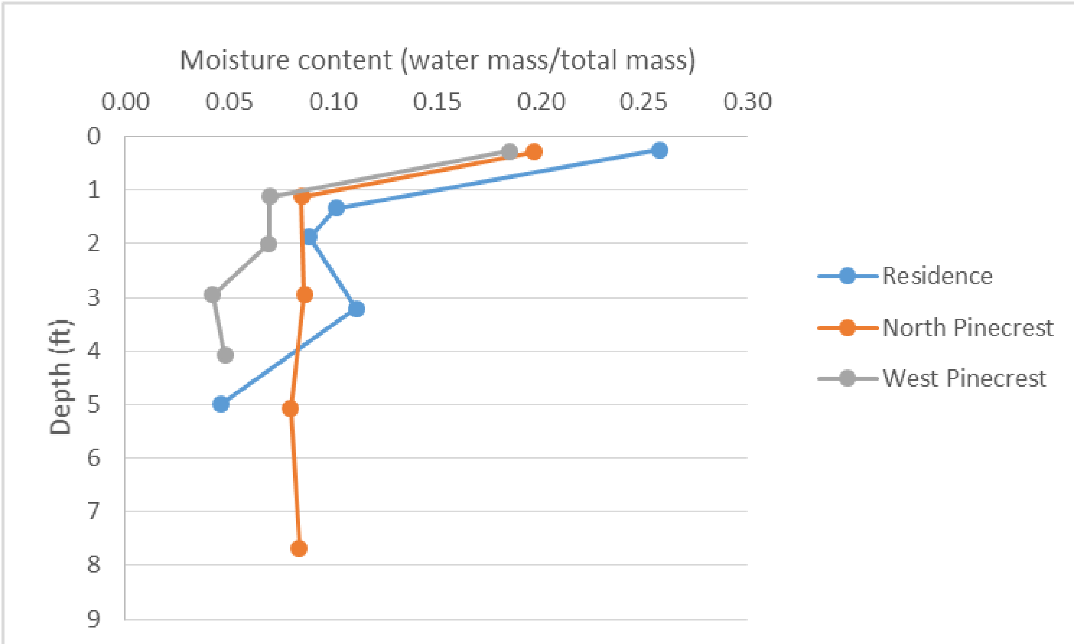


Fig. A16. Soil Moisture vs. Depth in Pinecrest Subdivision

The moisture content of the soil samples was high at the ground surface and low at depth, mainly due to rain events. These rain events provided enough water to moisten the soil near the ground surface but not at depth (Fig. A16). Unlike the other samples, the moisture content for the RES at 3.21 ft increased, which could indicate a locally perched water since the moisture content decreased at a depth of 5 ft.

A4.1.6 Electrical Conductivity

Overall, the soils in the Pinecrest Subdivision were non-saline (electrical conductivity < 1000 µS/cm). The average electrical conductivity was 11.25 µS/cm. The samples outside of the Pinecrest Subdivision had the highest conductivity at the ground surface with decreasing conductivity at depth. The conductivity at the RES exhibited a different trend from those outside the subdivision, with the highest conductivity at 3.21 ft and the lowest conductivity at the ground surface (Fig. A17).

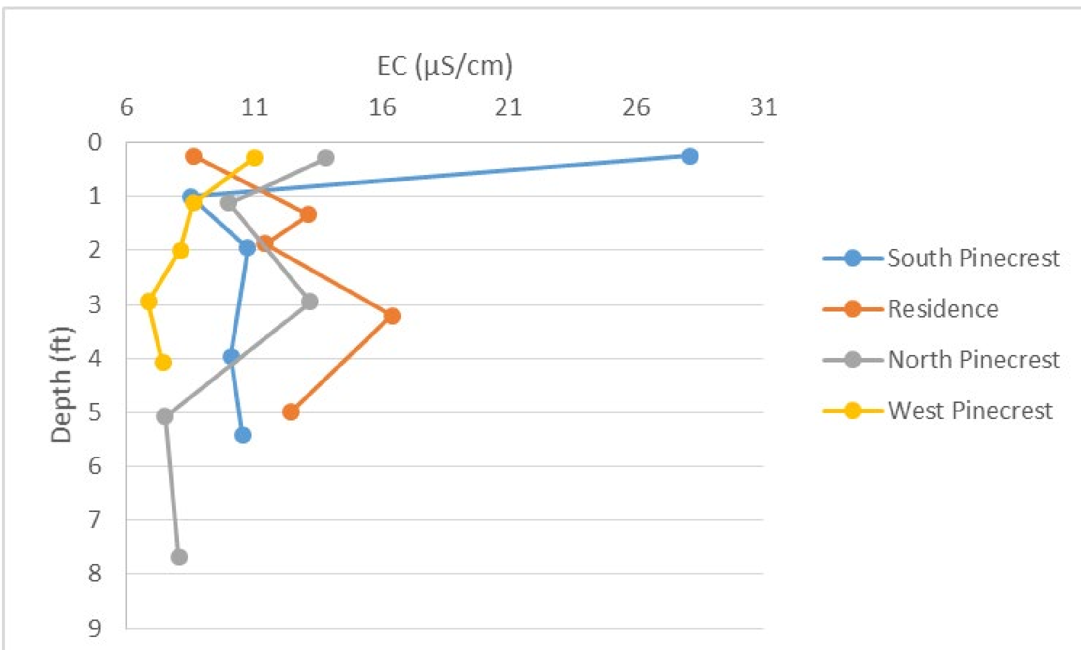


Fig. A17. Electrical conductivity (EC) vs. depths in Pinecrest Subdivision

A4.1.7 Nitrate

Relatively low concentrations of nitrate were recorded for all of the soils from outside the Pinecrest Subdivision (<1.22 mg/kg of soil) (Fig. A18). The sample from within the Pinecrest Subdivision had the highest nitrate concentrations, with the maximum nitrate concentration of 28.49 mg/kg at a depth of 3.21 ft.

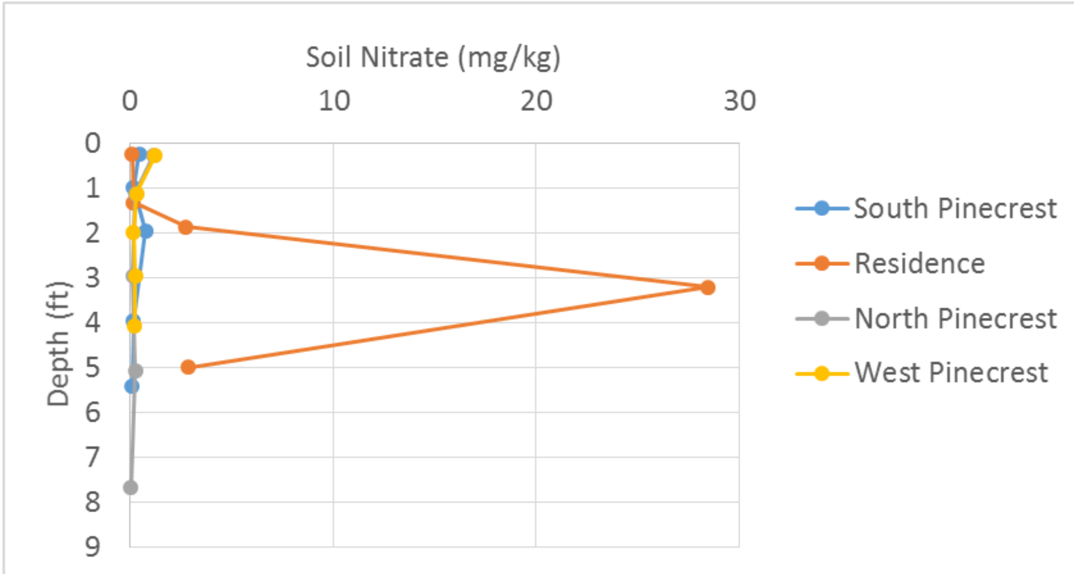


Fig. A18. Soil Nitrate vs. Depths in Pinecrest Subdivision

A4.1.8 Ammonia

Ammonia concentrations were low, with little difference between sites. The average ammonia concentration was 0.95 mg/kg. The NPC and WPC exhibited higher ammonia concentrations at the ground surface (1.22 mg/kg, 1.85 mg/kg), decreasing with depth (Fig. A19).

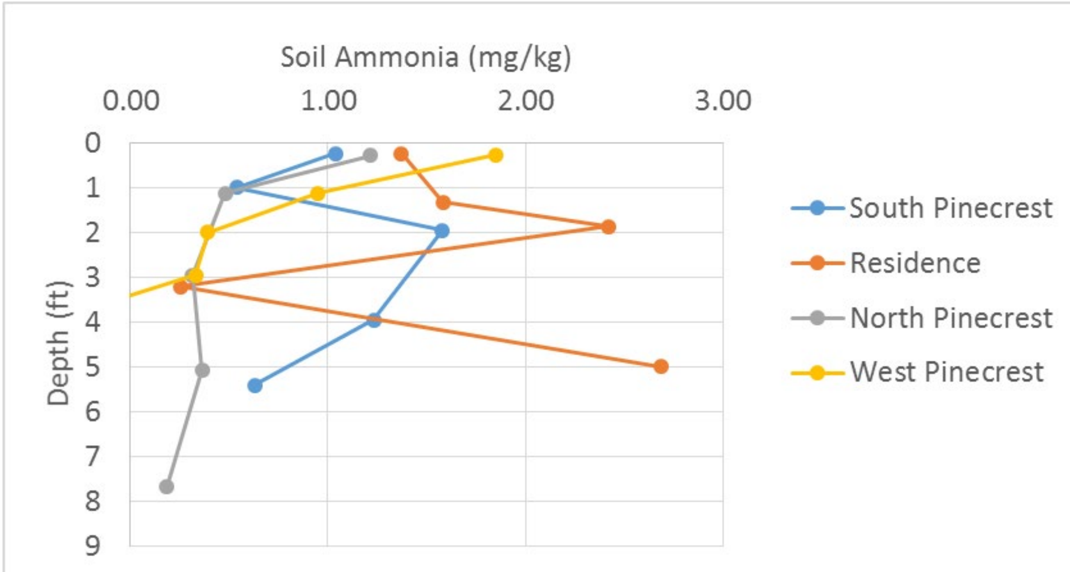


Fig. A19. Soil Ammonia vs. Depths in Pinecrest Subdivision

A4.1.9 Organic Matter

Organic matter was measured as a ratio of mass of organic matter to dry mass of soil. The samples followed the common trend of organic matter concentrations in soil, with the majority of organic matter in the top 3.28 ft (1 m) of soil and with the highest organic matter concentration near the ground surface (Fig. A20). The sample taken at the RES had the highest organic matter content and had a slower rate of decrease in organic matter with depth, because there are higher densities of mature trees in the subdivision and lower density of less mature trees on the BLM land outside of the subdivision. The more mature trees in the subdivision have had longer to grow, allowing their roots to grow deeper.

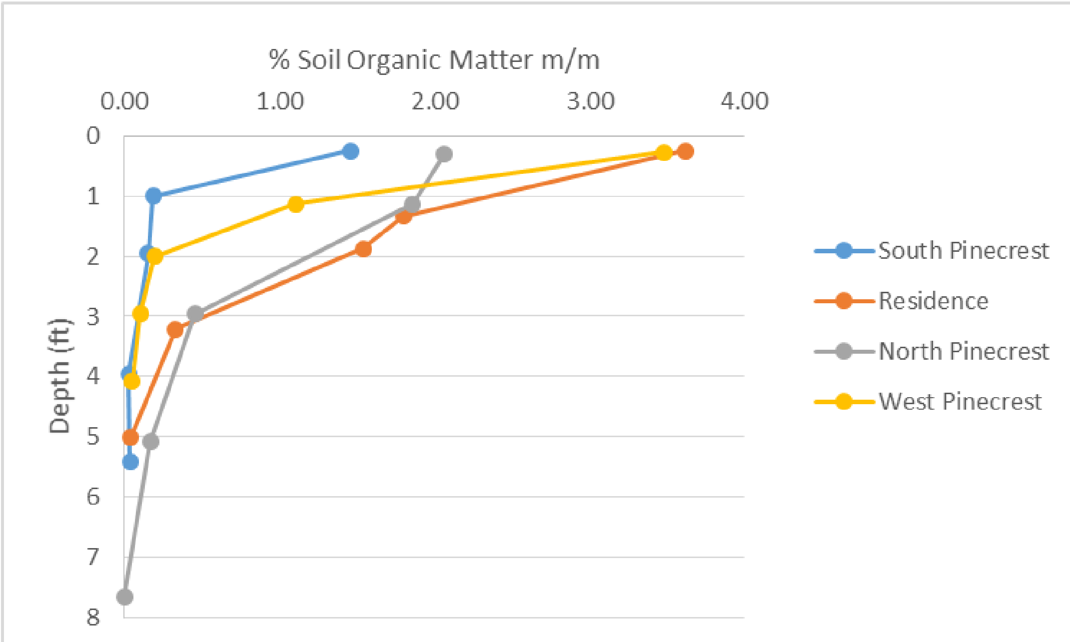


Fig. A20. Organic Matter vs. Depth in Pinecrest Subdivision

A4.1.10 Total Nitrogen

The total nitrogen concentration was measured from the dry <2 mm portion of the sample, using the same instrument as for the soil carbon content. The nitrogen content followed a similar pattern as organic matter, with higher nitrogen concentrations at the ground surface and decreasing concentrations with depth (Fig. A21). The only exception to this trend was samples from SPC, which had concentrations of 0.043 %N at the ground surface, decreased to 0.005 %N at 1 ft, and then increased to 0.009 %N at 1.96 ft.

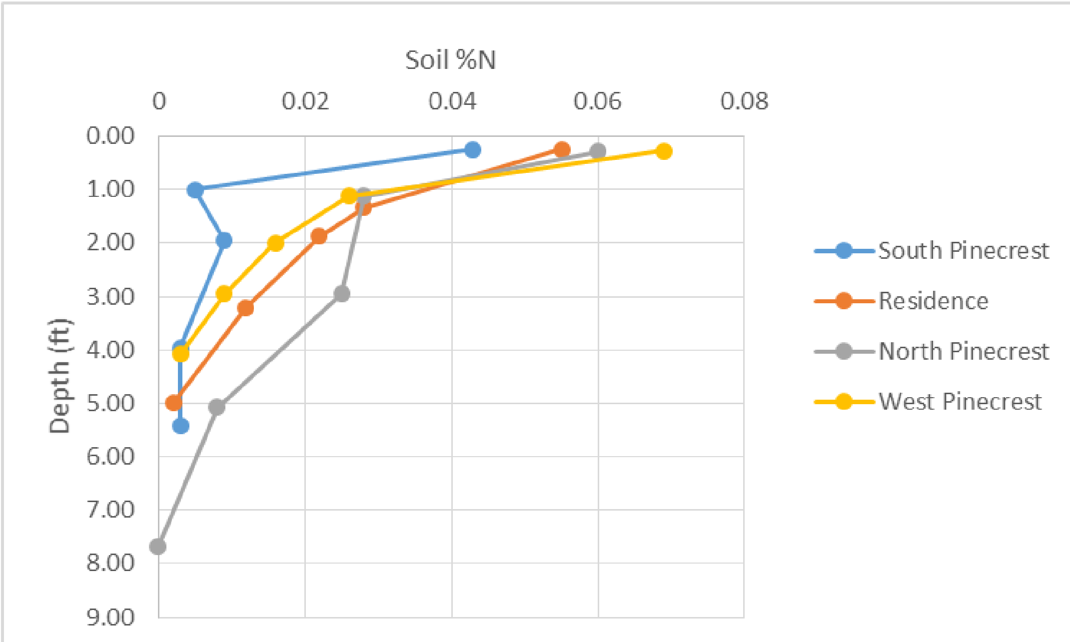


Fig. A21. Soil Nitrogen vs. Depth in Pinecrest Subdivision

A4.1.11 Soil Texture

The USDA particle size scale was used to classify the soils, with gravel (76.2–2mm; 3in.–0.079 in.), sand (2-0.05 mm; 0.079–0.002 in.), silt (0.05-0.002 mm; 0.002–8*10^{-5} in.), and clay (<0.002 mm; 8*10^{-5} in.). Fine materials were classified using the USDA Soil Textural Triangle.

From visually examining the soil while gathering samples in the field, there appeared to be three main layers of soil. The topmost O horizon (organic rich soil layer) ranged from the ground surface to 6 to 12 inches deep and consisted of coarse pumice sand mixed with fine-grained organic matter. There was a sharp horizon change from the O horizon to the horizon below, which was composed of tan/white pumice sand. Starting at a depth of 3 ft, the sand became darker black/brown with increasing gravel content with depth.

The gravels were mainly composed of angular to rounded pumice which varied in color, including black, grey, red, and brown. Some of the pumice looked like other types of rock due to weathering but was identified as pumice when fresh surfaces were examined. Ten percent of the gravel was composed of aphanitic vesicular (<0.3 mm in diameter), mafic basalt. One clast of gravel contained ~5% plagioclase, and 90% of the aphanitic gravel had a layer of quartz on one side. The transition between horizons at 3 ft was not sharp, and there was a transition as the material become more gravelly and darker with depth.

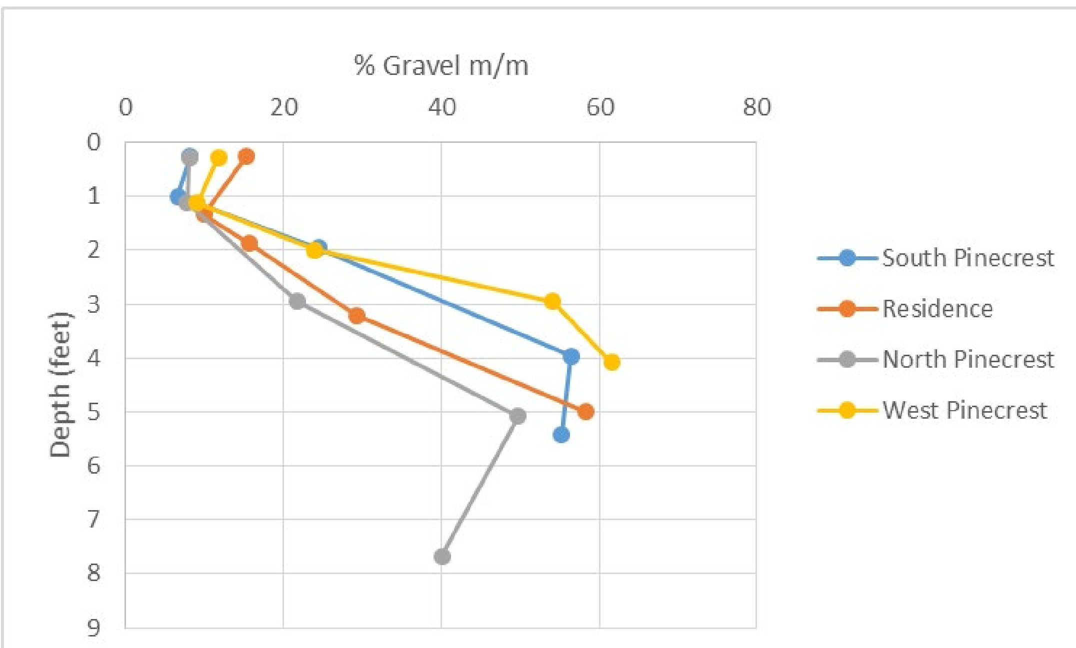


Fig. A22. Soil Gravel vs. Depths in Pinecrest Subdivision

The soils in the Pinecrest Subdivision were mainly composed of gravel and sand, with lower concentrations of silt and clay. The main soil textures for coarse material were gravelly (15-30% gravel) and extremely gravelly (30-60% gravel). The main textures of the <0.2 mm soil fraction in the subdivision were loamy sand

and sandy loam, with some sand at lower depths, which had increasing sand content (Table A15).

Table A15. Total Soil Classification in Pinecrest Subdivision

SPC		RES	
Depth (ft)	Texture	Depth (ft)	Texture
0.25	Sandy Loam	0.25	Sandy Loam
1.00	Loamy Sand	1.33	Sandy Loam
1.96	Gravelly Sandy Loam	1.88	Gravely Loamy Sand
3.96	Extremely Gravelly Sandy Loam	3.21	Extremely Gravelly Sandy Loam
5.42	Extremely Gravelly Sand (Gravel)	5.00	Extremely Gravelly Loamy Sand

NPC		WPC	
Depth (ft)	Texture	Depth (ft)	Texture
0.29	Loamy Sand	0.27	Loamy Sand
1.13	Sandy Loam	1.13	Loamy Sand
2.96	Gravelly Loamy Sand	2.00	Gravelly Sandy Loam
5.08	Extremely Gravelly Sandy Loam	2.96	Extremely Gravelly Sandy Loam
7.67	Extremely Gravelly Sand	4.08	Extremely Gravelly Loamy Sand

The <0.2 mm soil fraction was mainly composed of loamy sand or sandy loam; the exception was sand at 5.42 ft deep in SPC. The texture was not consistent across sample sites (Table A15).

The grain size with depth at NPC was comparable to grain size distributions with depth at the other sites (Fig. A23). These samples contained little clay. Clay comprised 11% or less of soil mass at all sites, with clay concentrations highest near the ground surface and decreasing with depth. Silt concentrations varied from 21% at the ground surface of the RES sample to 0% at the ground surface at WPC. Silt concentrations were highest at the ground surface of sampling sites or at a depth of 2-3 feet, and silt was <3.36% at all sites at the bottom depth. Sand concentrations were highest at shallower depths and tended to decrease with depth at all sites.

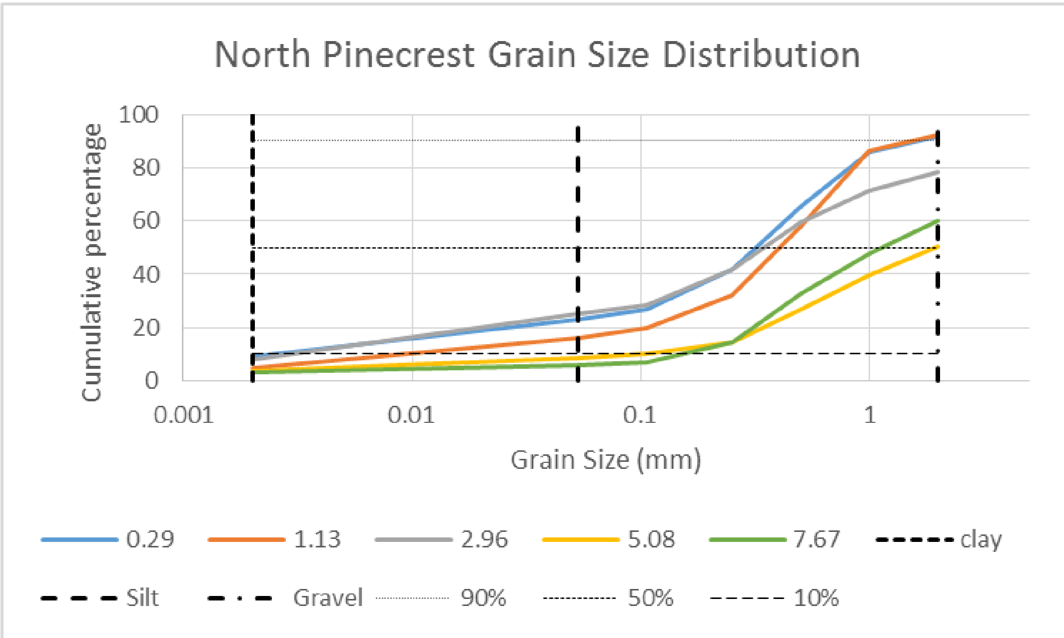


Fig. A23. Grain size Distribution at Depths (ft) at NPC

The results for soil texture were similar to the soil survey results for Shanahan Sandy Loam (Table A16), with increasing gravel and sand content with depth (USDA, 2018b). Though evidence of H2 (0.57-1.17 ft, gravelly loamy coarse sand) was not found, the gravelly horizons in (Table A15) are consistent with (Table A16).

Table A16. Soil Survey Textures

Shanahan loamy coarse sand		
Horizon	Depth (ft)	Classification
Oi	0-0.08	slightly decomposed plant material
H1	0.08-0.75	loamy coarse sand
H2	0.57-1.17	gravelly loamy coarse sand
H3	1.17 - 1.75	coarse sand
H4	1.75-2.25	loamy coarse sand
H5	2.25-3.17	sandy loam
H6	3.17 -3.75	gravelly sandy loam
H7	3.75-5.17	very gravelly coarse sand

*From (USDA, 2018b)

There were fewer horizons identified in this study than in soil surveys because it was not possible to resolve soil horizons using a hand auger to the degree possible through digging soil pits. Soils also tended to be heterogeneous, as shown by the differing gravel contents between samples (Fig. A22) and by the different textures between samples at the same depths in (Table A16).

One source of errors in these measurements was the hand auger, which only allowed for material smaller than ~1 in (25.4mm) to pass through its blades into the bucket. There were some coarser gravels in the bucket, which most likely fell into the bucket from above. Due to the selection of smaller grain size material by the auger, the gravelly soils may actually have had a higher percentage of gravel than represented. There would be a similar error when a drill was used to gather core samples, because the drill would break up some of the larger clasts of gravel.

A4.2 HYDRUS Simulations

The results for the HYDRUS simulations are divided into two parts. The first part pertains to the hydrologic conditions that were simulated in the simulations for La Pine and Laramie. The second gives more detailed analysis and comparisons of the simulations.

The first hydrologic conditions simulated were the rates of evapotranspiration in La Pine and Laramie from the simulations of soils from the ground surface to the depth of a leach field (Fig. A24 and A25). In the simulations, evapotranspiration rates were <50% of the rate of water infiltrating into soils from leach fields. Precipitation had a larger seasonal difference in La Pine, driving a large seasonal difference in evapotranspiration, whereas wind drove the variation in evapotranspiration in Laramie. When air is still, an equilibrium is reached between water in soil and water in the air near the ground's surface. During fast, dry winds, moist air near the ground is replaced with dry air, which causes more water to evaporate to move back to equilibrium.

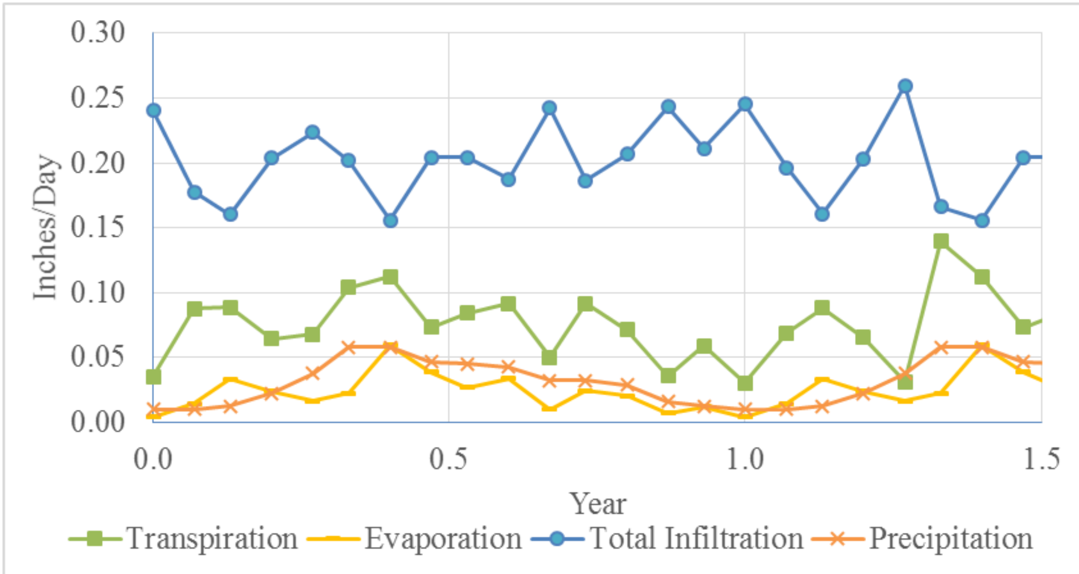


Fig. A24. Laramie HYDRUS Simulation of Water Fluxes

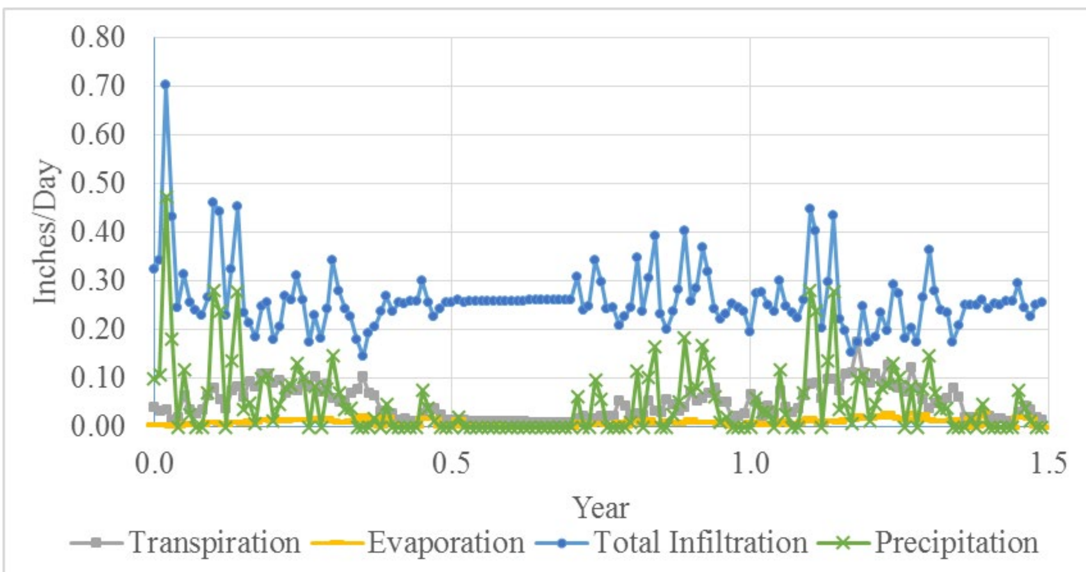


Fig. A25. La Pine HYDRUS Simulation of Water Fluxes

The simulated evapotranspiration in La Pine was similar to literature values during cold months (simulated 0.025 in/day, 0.024 in/day; Gannett et al., 2001), but simulated evapotranspiration was lower than literature values during warm months

(0.10 in/day simulated, 0.155; Gannett et al., 2001). These differences in evapotranspiration rates could be due to Gannett (2001) averaging the entire subbasin, including areas with much higher precipitation, while the HYDRUS simulation focuses on a dryer area of the subbasin.

The soil moisture content (Fig. A26) was used to show how quickly water from a septic system infiltrated through the vadose zone. In La Pine, it took septic system water ~ 0.2 years to reach the water table, and it took ~0.6 years to reach a depth of 46 ft. The velocity was greater in soils with wider pore spaces (sand), while the moisture content was smaller (clay sand).

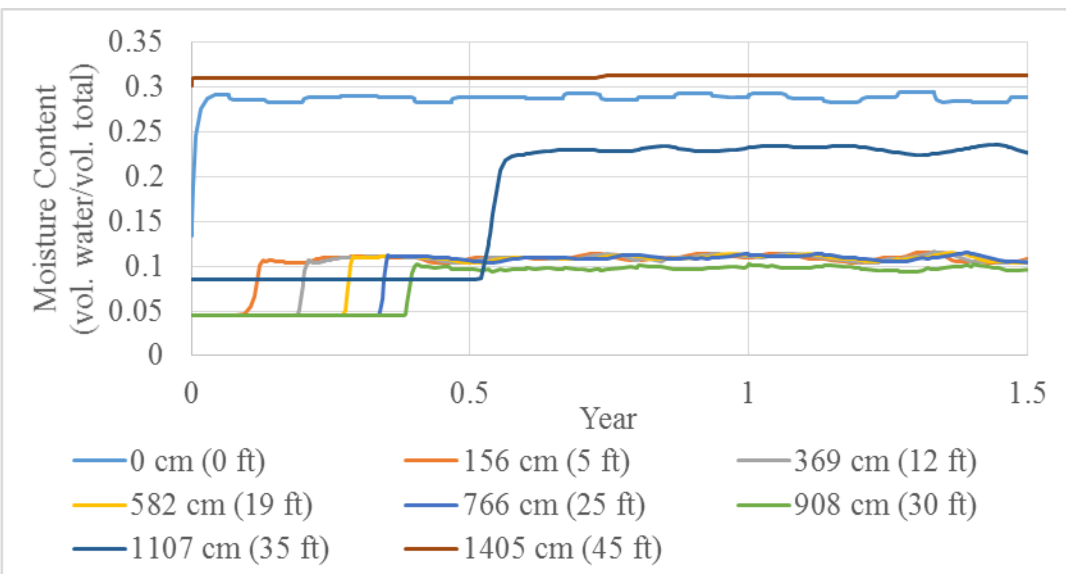


Fig. A26. Laramie HYDRUS Simulation of Soil Moisture
Depths in (ft)

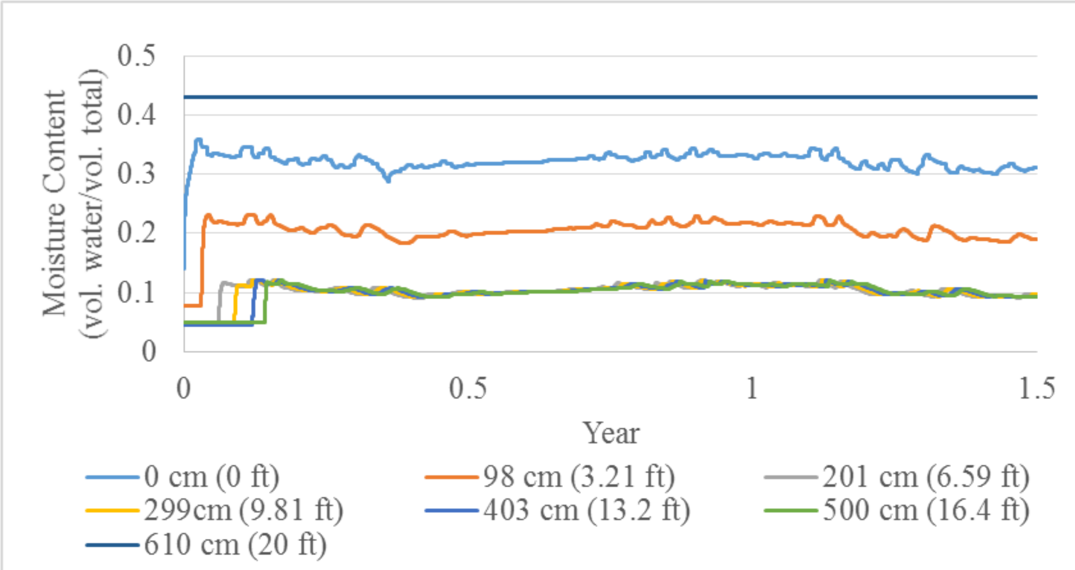


Fig. A27. Simulated Soil Moisture from La Pine based on Observed Soils

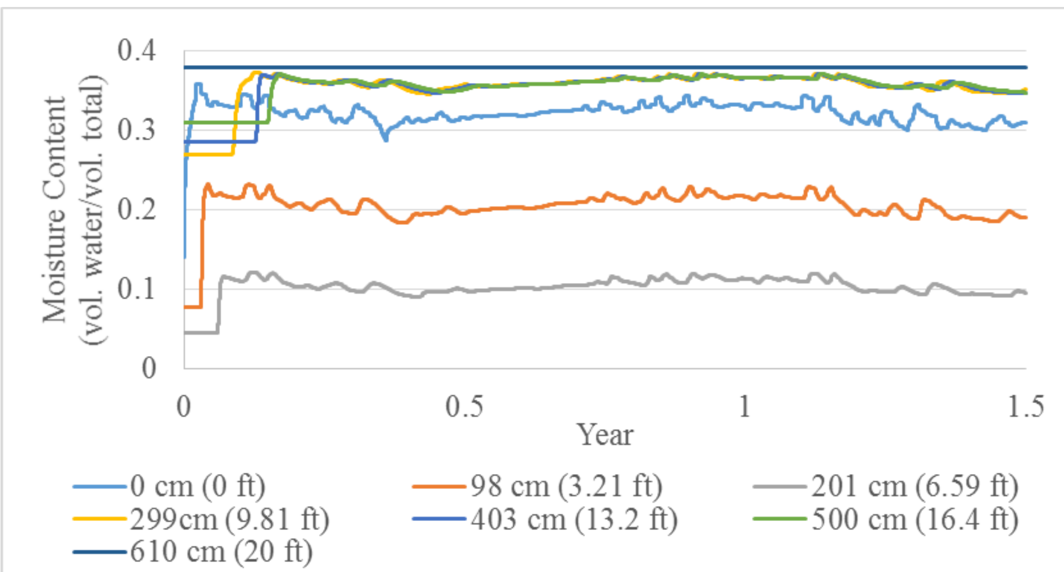


Fig. A28. Simulated Soil Moisture from La Pine based on Well Logs

The simulated nitrate concentrations (Fig. A29 and A30) show classic 1D contaminant plume behavior (Bedient et al., 1997). The nitrate was retarded (moved more slowly than infiltrating water) in the HYDRUS simulations, with more retardation in simulations with more sandy clay. The amount of retardation was unexpected since the absorbance parameters were low, so there should have been little retardation.

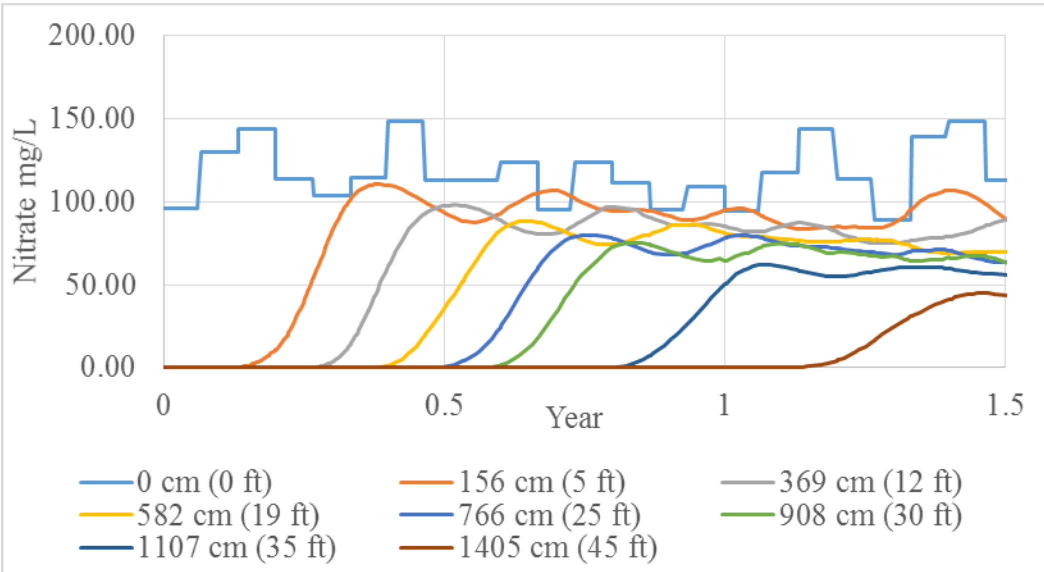


Fig. A29. Laramie HYDRUS Simulation of Water Nitrate
Depths in (ft)

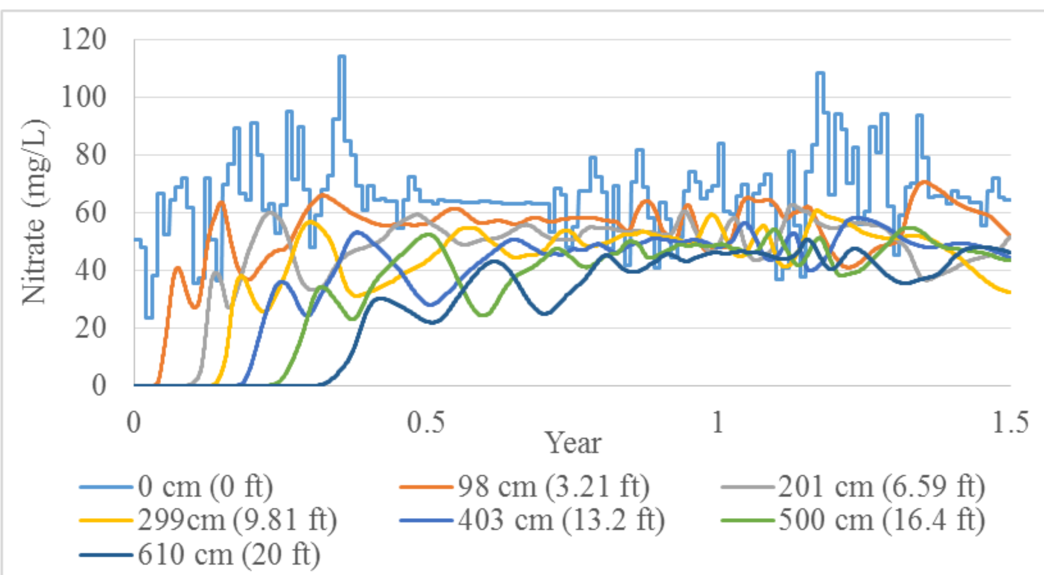


Fig. A30. La Pine Observed Soil HYDRUS Simulation of Water Nitrate

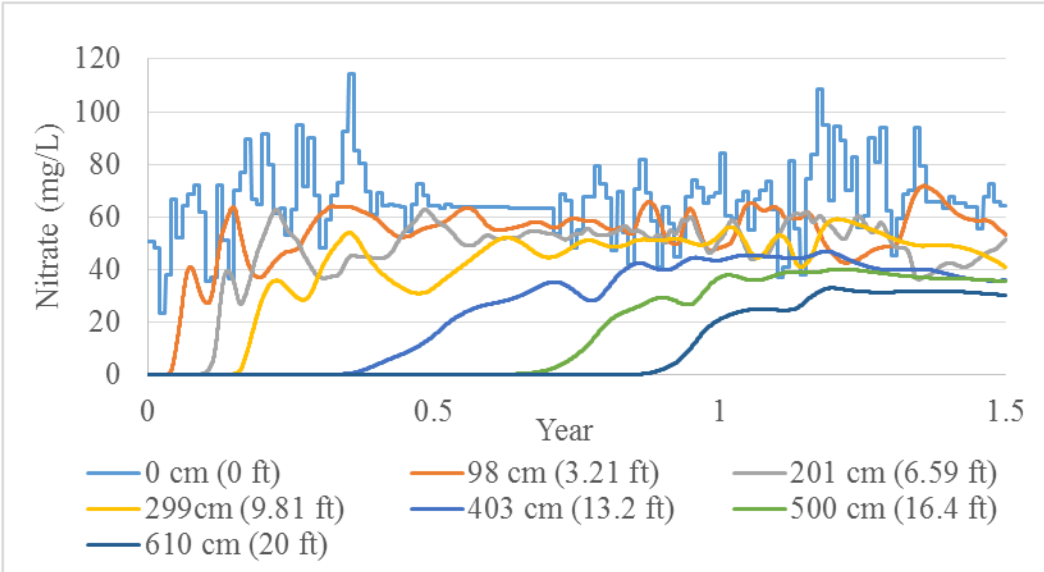


Fig. A31. La Pine Well Log HYDRUS Simulation of Water Nitrate

The simulated septic system nitrate concentrations in Laramie were adjusted so that simulated data from September 1st of the third year of the simulation was fit to observed nitrate concentrations (Fig. A32). The simulation parameters that fit the observed parameters were 75 mg/L of nitrate in septic systems and denitrification rates of 0.0016 day^{-1}. The 75 mg/L was within the ammonia concentrations observed in septic systems (94-70 mg/L; Wenck Associates, 2019). There were fluctuations in the simulation due to changing concentration of nitrate in wastewater from precipitation, evapotranspiration, and changing soil textures with depth.

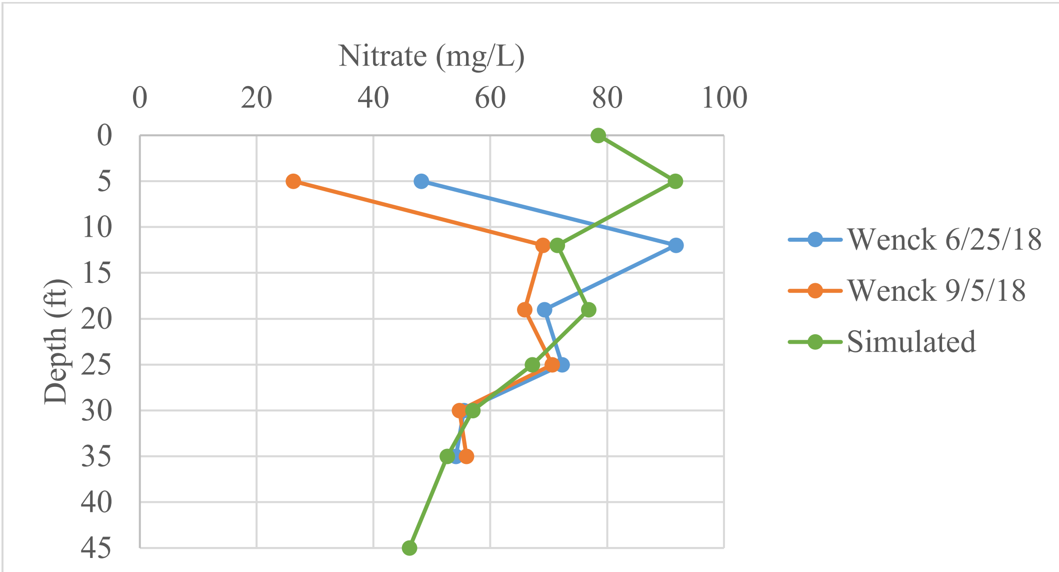


Fig. A32. Laramie Simulated and Observed Nitrate Concentrations

The denitrification rate from Laramie was used for the simulations in La Pine. Based on the simulations, the total denitrification in the vadose zone was 24% for the simulation based on observed soils and 40% for the simulation based on well logs (Fig. A33). The observed soil simulation matched closely with assumptions used in previous studies of 25% denitrification. The soil textures in the observed simulation most closely matched the sand filters used in previous studies (Morgan et al., 2007). Though the assumptions made in previous studies are reasonable, denitrification can still be variable in the area, as seen in the simulation based on well logs, in which sandy clay slowed water movement, leaving more time for denitrification to occur.

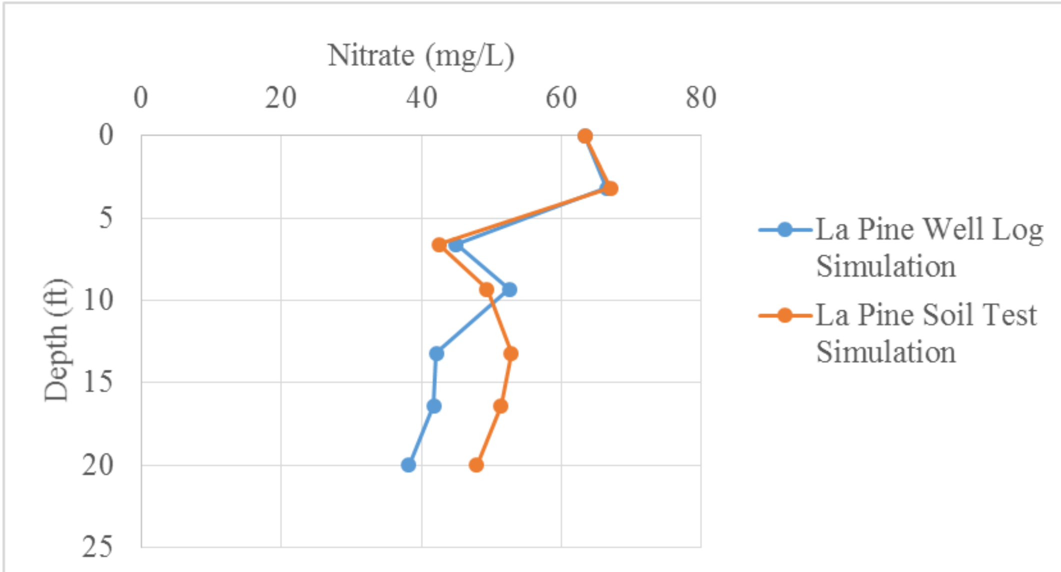


Fig. A33. Simulated and Nitrate Concentrations La Pine

A4.3 Real Estate Transaction Data

From the real estate transaction data from 2008 to 2018, 2 of 139 wells had nitrate concentrations of ≥10 mg/L, with the majority of wells having ≤1 mg/L of nitrate (Fig. A34).

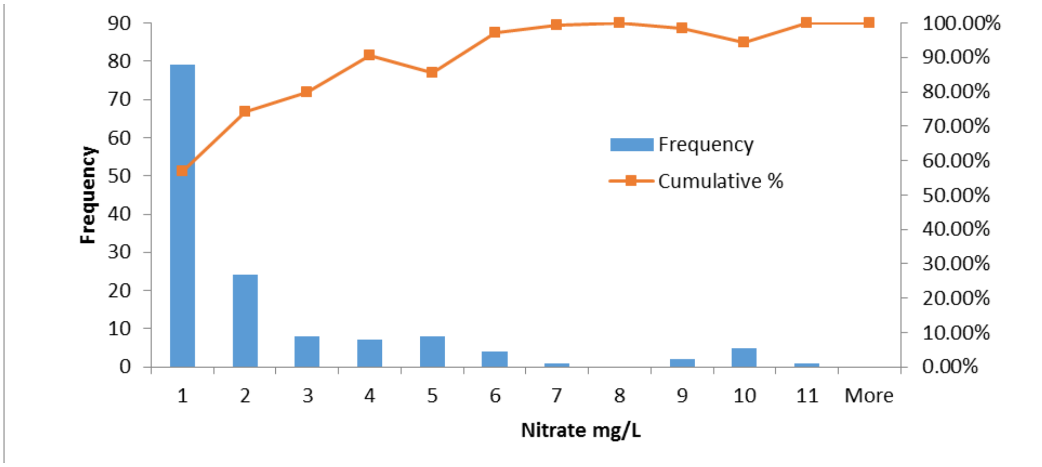


Fig. A34. Histogram of Real Estate Transaction Nitrate from 2008-2018, La Pine, OR
Explanation: Numbers on the x-axis represent number of samples equal to or below the value. Ex. The samples at 2 column had nitrate concentrations 1< and ≥2 mg/L.

The highest nitrate concentrations were found in the northern part of the City of La Pine and in subdivisions to the northeast of the city of La Pine (Fig. A35). Some of the high concentrations were highly localized, with little nitrate in nearby tested wells.

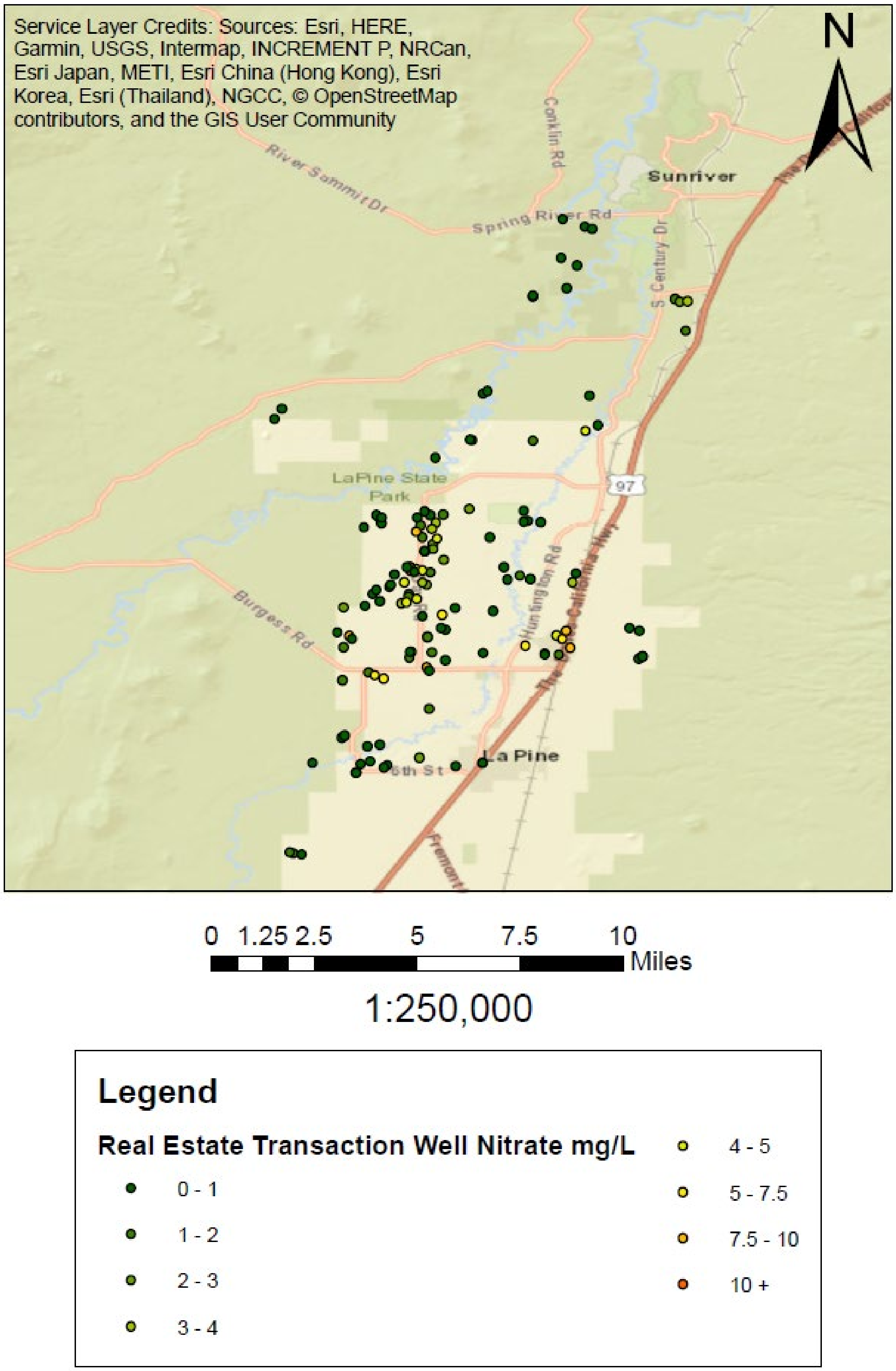


Fig. A35. Map of Real Estate Transaction Well Nitrate 2008-2018

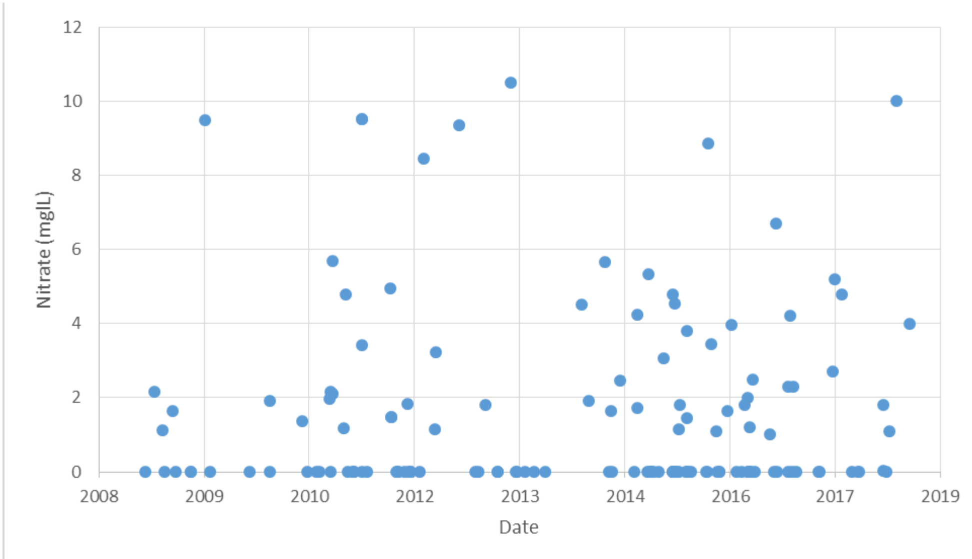


Fig. A36. Distribution of Real Estate Transaction Well Nitrate 2008-2018

A4.4 SWAT Simulations

The SWAT Model was used to predict nitrate concentration in groundwater for the La Pine Subbasin (Fig. A37). For most areas in the La Pine Subbasin, the nitrate entering groundwater was low (≤0.0053 lbs/acre, ≤0.0060 kg/ha), and the areas with higher nitrate (1.08-3.56 lbs/acre, 3-4 kg/ha) were in locations with high densities of septic systems.

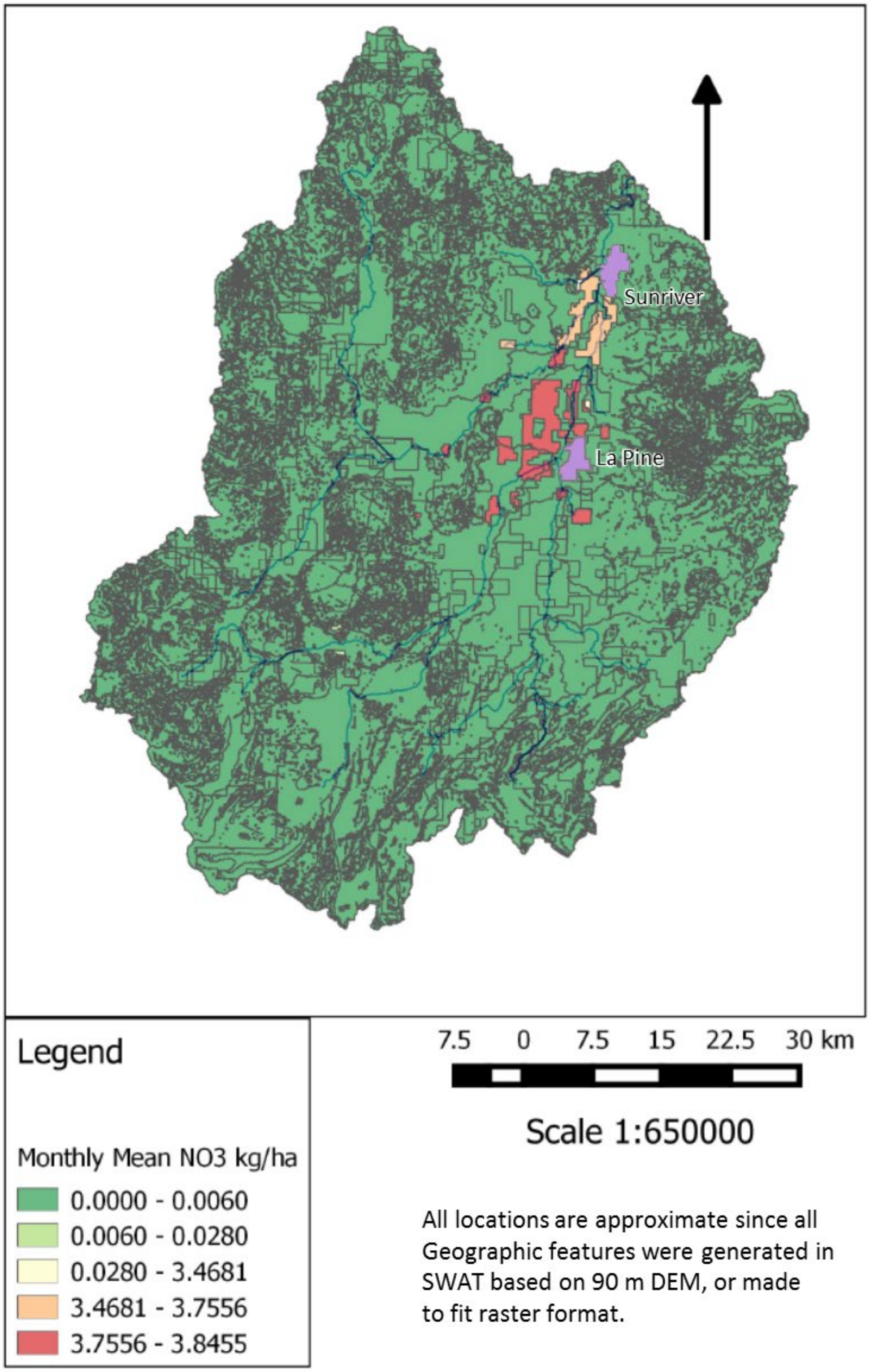


Fig. A37. SWAT Distribution of Nitrate in the La Pine Subbasin

Nitrate is regulated in mg/L, so the kg/ha of nitrate was converted to mg/L based on the predicted percolation of water into groundwater. This concentration would be higher than results found in actual well water, due to dilution by water present or possible lateral flow. The average monthly nitrate concentration in percolating water was graphed for the HRU with the highest amount of nitrate (Fig. A38). In the HRU, the nitrate concentration percolating to groundwater was approximately 2 mg/L. The concentrations of nitrate did not exceed the Oregon RL for nitrate in groundwater (10 mg/L) until the density of septic systems was doubled in the HRU.

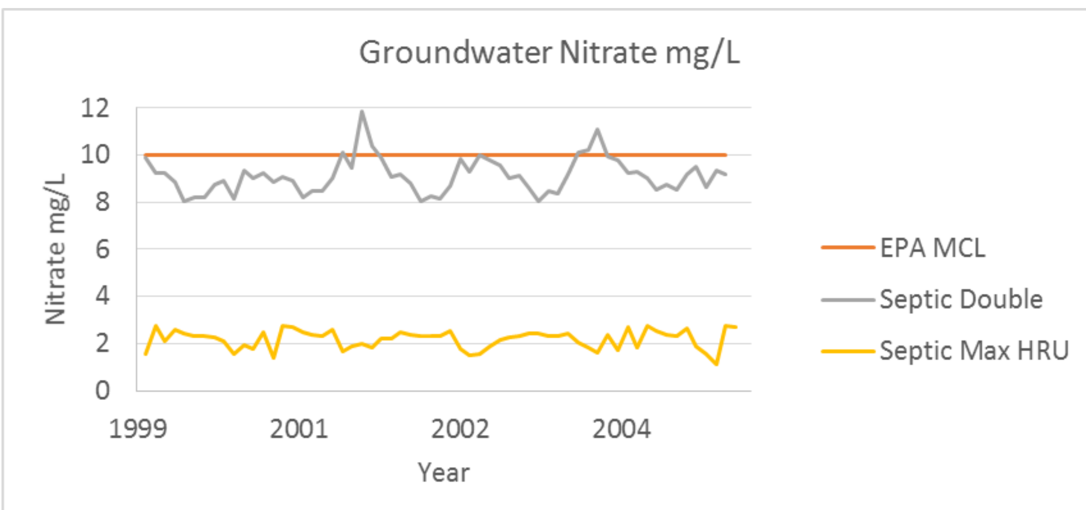


Fig. A38. SWAT Predicted Nitrate Concentration of Water Percolating to the Aquifer in HRU with Highest Nitrate Concentration

In simulations in which all the septic systems in an HRU failed, the concentration of percolating water rapidly increased to 60 mg/L (the concentration of nitrate in effluent). Surface water flowing out of the watershed was predicted to have some nitrate from septic systems, and results mirrored those predicted using the

HYDRUS Model, with lower concentrations during times with high precipitation, as described in a later section.

The SWAT model includes a wizard which can display total nitrogen and water balance for the watershed. Because the wizard uses units of kg/ha for nitrate and mm for water, Fig. A39 and Fig. A40 were adapted to measure total yearly nitrate in lbs and ft^3 for water. The total flow of water from the La Pine Subbasin was modeled to be 37 m^3/s (1300 ft^3/s), and the average discharge for this time period from Benham Falls was 33 m^3/s (1173 ft^3/s).

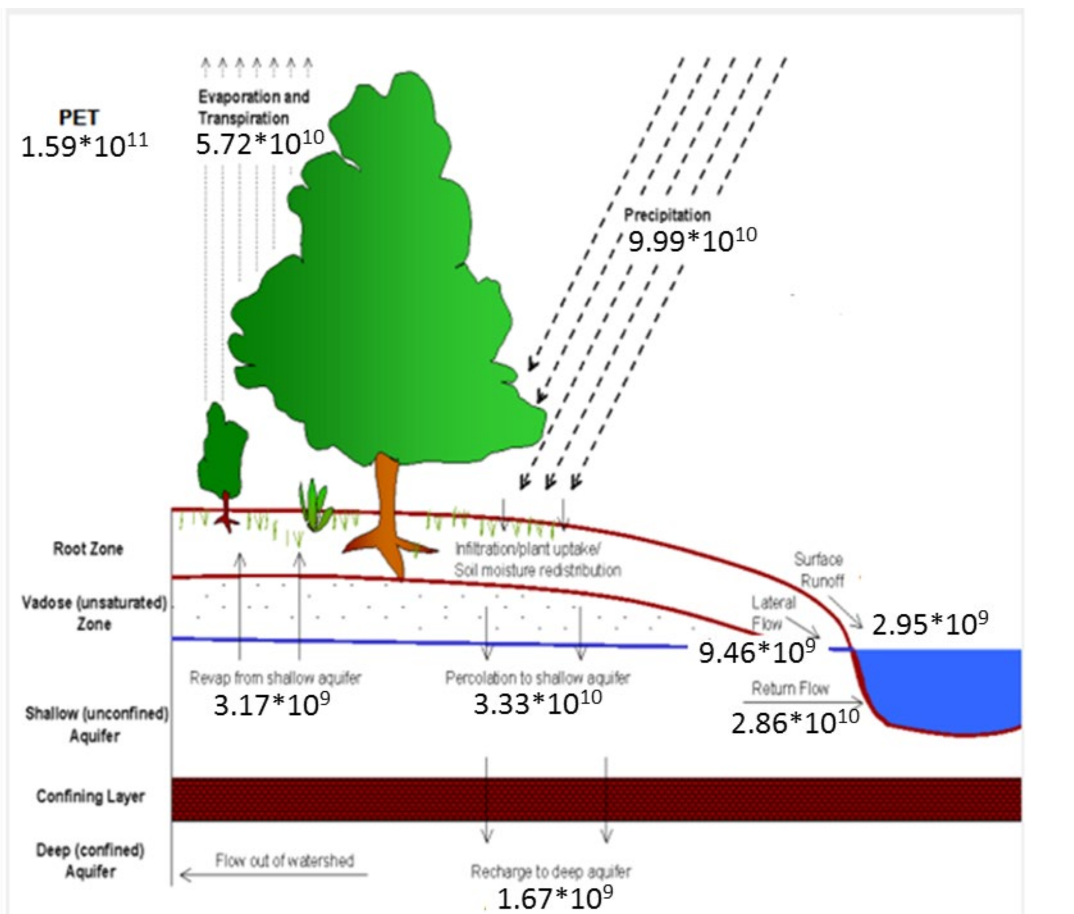


Fig. A39. Hydraulic Cycle of the La Pine Subbasin (ft^3/year)
Adapted from SWAT.

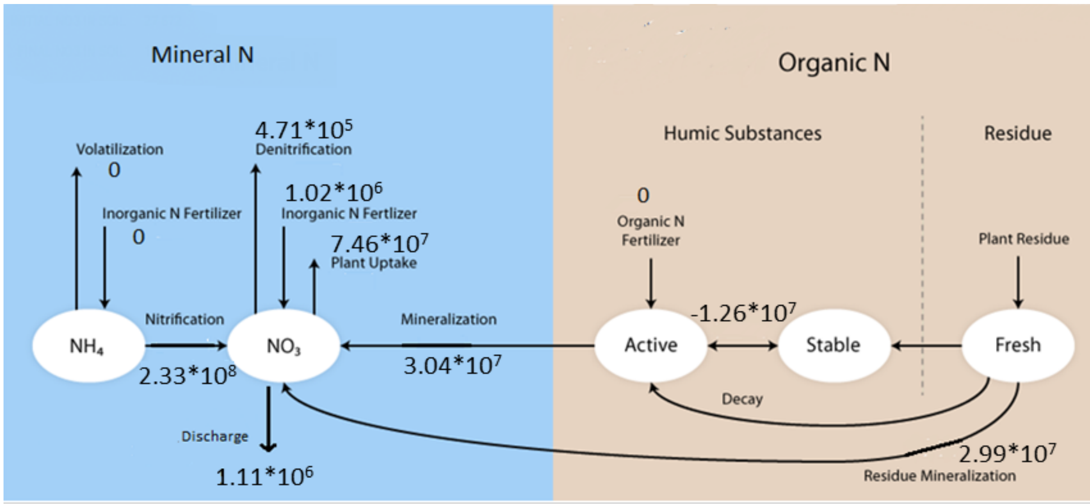


Fig. A40. Nitrogen Cycle for the La Pine Subbasin (lbs/yr)
Adapted from SWAT.

In the SWAT model, the predicted influx of nitrate was much higher than the nitrogen loss. The main pathway for nitrate creation was nitrification ($1.06*10^8$ kg, $2.33*10^8$ lbs), which was mainly from septic systems (Fig. A40). The degradation of organic matter was the next largest contributor to nitrate concentrations. Ideally, there should be little to no nitrate input from fertilizer (there was little plant-based agriculture besides timber), but it was included in the SWAT model as part of land use. The main way nitrate was removed from the system was via plant uptake, followed by discharge from the watershed, followed by denitrification.

A5. Discussion

A5.1 Soil Sampling Discussion

There were two main findings from the vadose zone soil study in the La Pine Area: (1) soil conditions within subdivisions are different from those outside subdivisions; (2) nitrate testing was the most valuable analysis for explaining

NOWTS in the vadose zone, and while other analyses contributed to the results, there was more uncertainty in the interpretation of those analyses.

The samples from the RES site (located within the subdivision) exhibited a different trend from the samples outside of the subdivision. The most prominent difference was a peak nitrate concentration (28 mg/kg) at 3.21 ft in the RES sample, whereas the highest concentration at all other sites was 1.2 mg/kg at the ground surface at the WPC sampling site (Fig. A18).

The cause of the spike in nitrate concentrations remains uncertain because there are many potential sources of nitrate and none of the other results show as large a difference between the RES site and other locations. For example, total nitrogen (Fig. A21) exhibited a similar trend of decreasing with depth at all sites.

When comparing the different types of nitrogen at the RES site (Fig. A41), the main form of nitrogen in the soil was organic matter. Nitrite, nitrite, and ammonia comprised a small portion of the total nitrogen. The nitrate concentration at the RES sample occurred when ammonia concentrations were the lowest, which could indicate nitrification.

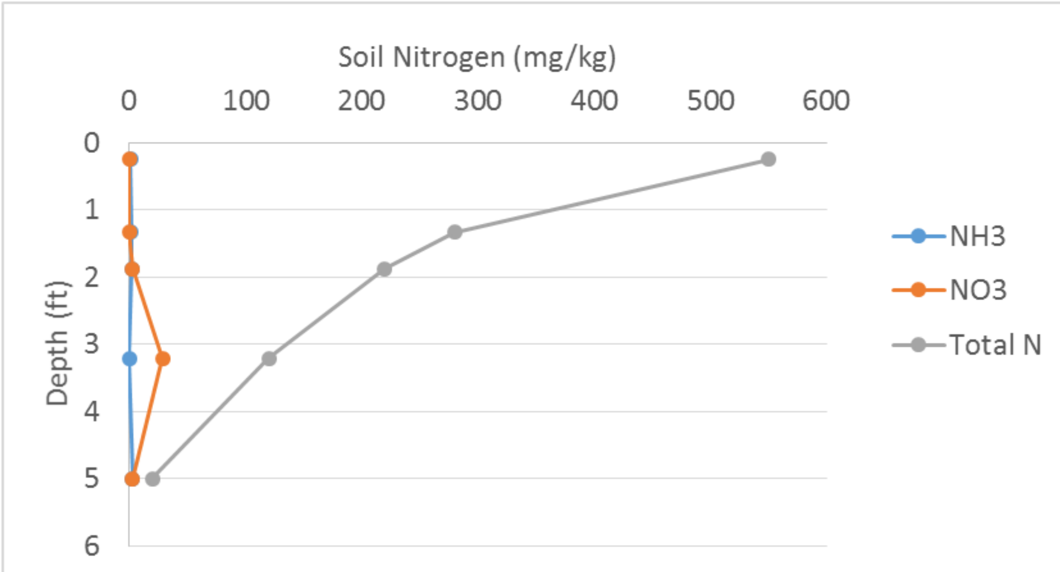


Fig. A41. All Forms of Nitrogen at RES

The lines of evidence supporting septic systems as the source of nitrate from RES samples were as follows:

- The nitrate at the RES site spiked at a depth of 3.21 ft, which is approximately the same depth as a leach field.
- The nitrate spike at RES was an order of magnitude larger than at any of the other sample sites.
- The highest electrical conductivity (Fig. A17) and moisture (Fig. A16) in the RES sample were at the same depth as the nitrate spike**.**
- Electrical conductivity is often associated with salts and ions in wastewater.

The lines of evidence suggesting that the high nitrate concentrations at the RES sample came from non-septic sources were as follows:

- At the RES site, there was more potential for nitrate from other human activities, such as fertilizers.
- Nitrate peaked at one depth in the RES site, which is more consistent with accumulation of nitrate from a more local source, such as fertilizer (Hanson et al., 2006).
- The closest leach field should have been >30 ft away from the sampling site; the nearest septic systems have been in place since 1979 (Pankratz, 2000).

- If the nitrate were from a septic system, nitrate concentration should be more evenly distributed at depths below 3.21 ft or increase at greater depths (Rolston et al., 1996).

Other potential reasons for the nitrate spike at the RES site could include:

- An accumulation of nitrate in the soil from fertilizer or other manmade sources (Fan et al., 2010).
- The degradation of organic matter or other natural processes (Schlesinger and Bernhardt, 2013).
- The higher density of older trees within the subdivision compared to outside of the subdivision, with rooting depths of 10 ft or deeper (Horton, 1958).

More data are needed in order to track the source of the nitrate, such as through the use of other tracers.

For this study, 10 types of soil analysis were conducted: pH in lab, pH/nitrate test strips, infiltration, soil moisture, electrical conductivity, nitrate, ammonia, organic matter, total nitrogen, and soil texture. The most relevant constituents analyzed were nitrate, ammonia, and total nitrogen, since they were the focus of this study and NOWTS. Soil moisture, electrical conductivity, and organic matter were used to frame soil conditions and processes that affect nitrate concentrations. Soil texture was mainly used for modeling the vadose zone. While pH and infiltration are measures of soil conditions that can affect NOWTS, they were not as relevant for this study. The pH/nitrate test strips were used because they had potential to be an inexpensive and simple test method which could be used by resident scientists. While pH test strips were relatively accurate, nitrate test strips were not accurate for the low concentrations of soil nitrate in La Pine. There were difficulties determining the color of test strips since dirt would accumulate on them.

A5.1.1 La Pine Compared to Other Locations

The types of NOWTS studies (Table A1) most comparable to the La Pine vadose zone study either used lysimeters to study vadose zone water (Hinkle et al., 2005; Weaver, 2014; Wenck Associates, 2019) or studied soil samples (Rolston et al., 1996; Izbicki et al., 2015; Wenck Associates, 2019).

In previous work in La Pine (Hinkle et al., 2005), total nitrogen concentrations were 71-99 mg/L in a septic system, nitrate was 32.7-67.2 mg/L in lysimeters >60 cm beneath a leach field, and 4.3-7.0 mg/L of nitrate was measured in groundwater beneath a leach field.

In a study in Ontario, Canada, lysimeters were placed <3.3 ft (1 m) beneath leach fields at commercial and residential locations to collect nitrate samples. Nitrate concentrations were highest 10 cm beneath a leach field (40-62 mg/L nitrate) and decreased with depth (0-30 mg/L nitrate), except for one location in which all depths had similar concentrations (10 mg/L nitrate). The Weaver (2014) results were similar to Hinkle et al., (2005) in that nitrate decreased with depth, except that nitrate concentrations were more variable. The differences could be due to differences in the climate and soils between La Pine and Ontario or to differences between systems for residential versus for commercial use.

Compared to the study in Ontario, lysimeter readings were taken at greater depths (5-35 ft beneath leach fields) in Laramie, WY (Wenck Associates, 2019). Results differ between Laramie and Ontario (Weaver, 2014) because nitrate concentrations were low near the septic system and increased with depth before decreasing. The Laramie results agree more with La Pine (Hinkle et al., 2005), where there was less of a decrease in nitrate in the vadose zone.

In a study in Davis, CA, soils were collected from between two leach field lines which were 25 ft apart (Rolston et al., 1996). The soil nitrate concentrations in Davis were similar to those from this study, in which there was a peak in nitrate concentrations at a shallow depth with a consistent increase starting at 30 ft. This would agree with the present study if the nitrate near the ground surface was from surface processes and the nitrate at depth was from septic systems, as it took 30 ft for the liquid from the septic system to disperse 12 ft horizontally.

In a study in Yucca Valley, CA, borings were drilled near residential septic systems and in undeveloped areas (Izbicki et al., 2015). The undisturbed site in Yucca Valley had similar nitrate concentrations to undisturbed sites in La Pine (Fig. A18), with a rapid decrease in nitrate concentration with depth and relatively low nitrate concentrations. The nitrate peak in Yucca Valley at sites with septic systems was similar to the nitrate peak in La Pine (Fig. A18), but the depths are different: 3.21 ft in La Pine and 25 ft in Yucca Valley.

In Laramie, soil nitrate concentrations ranged from 1.9 mg/kg to 3 mg/kg, decreasing with depth beneath a leach field, and no nitrate was detected in soils in undisturbed areas (Wenck Associates, 2019). Soil samples in La Pine were at shallower depths (<8 ft) than samples in Laramie (>8 ft). The soil nitrate concentrations in soils affected by septic effluent in Laramie (Wenck Associates, 2019) were lower than soil nitrate concentrations found in Davis, CA (Rolston et al.,

1996) and in Yucca Valley (Izbicki et al., 2015). Undisturbed sampling sites from Yucca Valley and Laramie exhibited similar trends in nitrate concentrations (<1 mg/kg).

In a unique study by a resident scientist exploring background concentrations of nitrate near a subdivision serviced by OWTS near Laramie, WY, soil nitrate ranged from 0 to 200 mg/L (Rovani, 2012). In comparison to La Pine, soil nitrate concentrations were much lower at <1.5 mg/kg (though Total N was 400 to 700 mg/kg) (Fig. A41). The high nitrate concentrations in surface soils near Laramie (Rovani, 2012) were attributed to native nitrogen-fixing plants and microorganisms. The differences could be due to methodology: in Laramie, soil samples were taken near plants to sample cryptogamic soils, while in La Pine, plants were avoided in order to decrease environmental impact and increase the convenience of sample gathering.

Soil nitrate concentrations from the RES site in La Pine exhibited different trends than in residential sites in Davis (Rolston et al., 1996) and Yucca Valley (Izbicki et al., 2015). The highest nitrate concentrations at the RES sites were at 3.21 ft (28 mg/kg), whereas they were at 45 ft (20 mg/kg) in Davis and 30 ft (50 mg/kg) in Yucca Valley. The borings in Davis (Rolston et al., 1996) and Yucca Valley (Izbicki et al., 2015) were closer to leach fields than the boring in La Pine, meaning that La Pine should have also had nitrate concentrations increase at greater depths than in Davis and Yucca Valley.

A5.1.2 Soil Sampling Limitations

The original goal of the study was to take soil samples from the entire vadose zone to a depth of approximately 20 ft. The depth of 20 ft could not be reached because the hand auger used to collect samples had difficulties penetrating a gravel layer starting at a depth of 3 ft.

Based on communication with ODEQ and community members before sampling, there was concern that the hand auger would not work, since hand augers had been used in the past but soil kept sloughing into the hole as it was dug. For the samples taken for this study, there was no issue with sloughing until the gravel layer was penetrated, and the auger deviated from the linear path as it was blocked by gravels.

There was no surface expression of gravel at the site. However, gravel was documented in soil surveys (USDA, 2018b), and gravel pits were documented in USGS maps created before the subdivision was developed. Well logs from the Pinecrest/Holmes Acres subdivision rarely mention a gravel layer, though some logs do mention pumice. In the La Pine Area, locals used the term “pumice” to describe the sandy soil in the area as well as gravels composed of pumice.

Multiple paths were pursued in an attempt to continue sampling. The first was to use powered drilling equipment to bore through the gravel layer. However, on land administered by the Bureau of Land Management (BLM), the use of powered drilling equipment required permits. While the permits were pursued, final permits were not received until years later.

Alternate sampling locations were also considered, with potential locations including the ranches to the north and east of the Pinecrest/Holmes Acres Subdivision and the railroad to the east of the subdivision. Attempts to contact the landowners of the ranches were unsuccessful, and the railroad did not allow sampling.

Residents within the Pinecrest Subdivision were reticent to allow powered drilling equipment on their property. By contrast, participants in the study who lived in other areas were more willing to allow drilling on their property. Drilling in these locations was not pursued, because the residences were far from the Pinecrest/Holmes Acres Subdivision and federal agency permission is required for background samples.

Future studies could use power drills to sample borings at different distances from leach fields on private property. This bypasses the need for permits to drill on public land, and the impact of septic systems on the vadose zone can be determined based on the distance from the leach field.

Though anticipated sampling depths were not reached, modeling and comparison to existing literature were used to estimate possible conditions.

A5.2 HYDRUS Discussion

Many assumptions were made for the HYDRUS simulations. Though the simulations represent what is expected to happen at each location, actual conditions may vary. Based on the assumptions made as part of modeling, actual flows and movement of nitrate should be slower than those in the HYDRUS simulations because the lateral movement of water was not simulated.

The HYDRUS model could be improved by using HYDRUS 2/3D, which can model in more directions that HYDRUS 1D and which allows boundary conditions to be placed underground. Using HYDRUS 2/3D, all factors can be included in one simulation instead of having to use multiple simulations to correct for boundary conditions and evapotranspiration. The HYDRUS 2/3D model was not used because licenses were costly and copies at OSU facilities had either expired licenses or other technical problems, whereas HYDRUS 1D is free to use.

A5.3 Real Estate Transaction Data Discussion

The real estate transaction data matches previous data for the La Pine Area and models for the La Pine Area, where there is little discernable trend over time (Morgan et al., 2007; Huddle, 2012). Reasons for there being little trends include the expansion of sewer and public water, the fact that the platted lots had not been fully developed, and the use of nitrate-treating OWTS in newer developments.

ODEQ and CAG were concerned with the quality of real estate data because:

- There was little oversight of the program.
- Realtors collected and submitted samples for testing, but wells were not always tested and results were not always submitted.
- Realtors may not have collected samples or submitted results correctly.
- Some sample collection and sampling dates exceeded the holding time for nitrate (48 hours, EPA 200.7).
- There was a conflict of interest in that it was in the interest of realtors for wells to have low nitrate concentrations.

A5.4 SWAT Discussion

The SWAT Model predicted elevated nitrate concentration in areas with subdivisions on septic systems (Fig. A37). In the area with the highest nitrate concentration, nitrate in groundwater was predicted to be 2 mg/L (Fig. A38). The concentrations of nitrate did not exceed the Oregon reference levels for nitrate in groundwater (10 mg/L) until the density of septic systems was doubled. The nitrate concentration predicted in SWAT (2 mg/L) was relatively close to the average nitrate concentrations of real estate transaction data (1.6 mg/L).

The SWAT model predicted that the influx of nitrate would be higher than the nitrogen loss (Fig. A40). The main pathway for nitrate creation was nitrification ($2.33*10^8$ lbs ($1.06*10^8$ kg)), which was orders of magnitude higher than the 150,000 lbs/yr estimated in previous studies (Morgan et al., 2007). The main way nitrate was removed from the system was via plant uptake, followed by discharge from the watershed and denitrification.

Actual conditions were used as the inputs for the model in as many places as possible, but there were some areas where the simulation did not match actual conditions (Fig. A42). Precipitation and discharges could not be simulated because of the high variability of precipitation in the watershed and the large reservoirs in the watershed, which dominated flows.

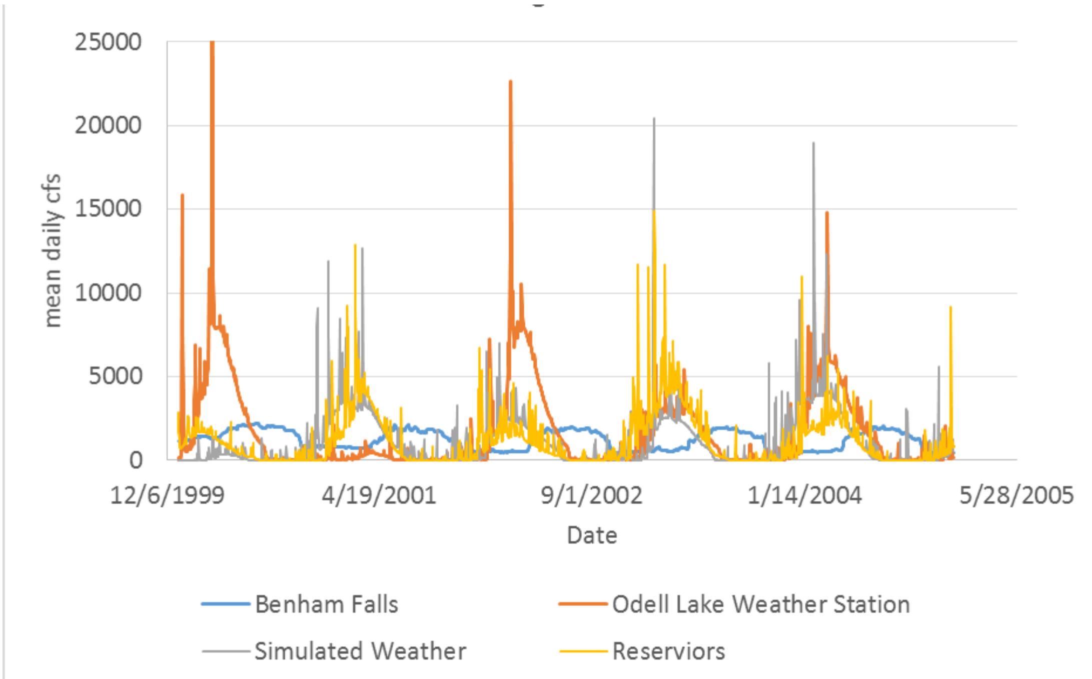


Fig. A42. Actual and SWAT Simulated Discharge from the La Pine Subbasin
Explanation: Benham Falls represents observed discharge from the watershed, while the other curves represent simulations of discharge.

The SWAT simulation had a worse resolution than previous models of the La Pine Area because nitrate concentrations were averaged over a larger area (Morgan et al., 2007). Predictions could not be made at the well scale, which was of most concern for stakeholders (Huddle, 2012). This suggests that nitrate from septic systems may be better modeled as a point source pollutant rather than a nonpoint source pollutant.

A5.4.1 Comparison of HYDRUS, SWAT, and Models from Other Studies

Though the SWAT and HYDRUS models simulated NOWTS, the scale and processes used in the models were very different. In the HYDRUS simulations of La Pine, infiltrating water exhibited concentrations of approximately 40-50 mg/L nitrate when it reached the aquifer (Fig. A33), while SWAT estimated that the nitrate concentration would be 2 mg/L. The HYDRUS concentration was higher because it represents more concentrated septic effluent in the vadose zone directly beneath a septic system, whereas SWAT represents the average over an area of which only a small portion is covered by leach fields.

The HYDRUS and SWAT models had limited resolution and scope compared to previous studies in La Pine (Morgan et al., 2007). While it is possible to make models with higher resolution, there are limitations in model stability, processing power, and run time. There were also missing or inaccurate records of septic systems and wells, which made the model inaccurate. The difficulty would further increase if attempts were made to include local knowledge. Any nitrate model at the time of this study would be inaccurate due to the low resolution and the complexity of hydrology and the nitrogen cycle.

The HYDRUS model used for this study was comparable to models in Carsel (1996) and Izbicki (2015). A model of nitrate movement beneath septic systems in Colorado showed similar denitrification rates to this study, with a 32% reduction in nitrate in the vadose zone and nitrate concentrations of 20-30 mg/L in water infiltrating from septic systems before mixing with the aquifer (Carsel, 1996). Modeling conducted in Yucca Valley, CA showed a 5% nitrate reduction in the vadose zone, but nitrate movement was based on house density, with slower movement for lower house density (Izbicki et al., 2015). The Yucca Valley model is different from the models used in this study and in Carsel (1996) due to the arid climate and deep aquifer in Yucca Valley.

A5.5 Transferability

In this study, soil nitrate laboratory measurements were the most transferable form of soil analysis to future work on NOWTS, given that nitrate gave the most direct measurement of NOWTS and had the greatest variation between samples. The other types of analysis played a less direct role in this study and aided little in the interpretation of nitrate results. The use of pH/nitrate test strips was useful as an indicator, but the strips were not accurate enough for technical studies.

Although the majority of stakeholders surveyed in La Pine understood the analysis, the use of fewer analyses would make the study more concise. In La Pine, studies of tracers to track the sources of nitrate (Hinkle et al., 2005, 2007, 2008) were helpful for the understanding of technical experts but less helpful for stakeholder understanding. More complex studies were mentioned less by stakeholders than studies which focused specifically on nitrate.

Some data were transferable between locations, as seen by the similar values for denitrification rates found in the HYDRUS models and other factors from similar NOWTS vadose zone studies.

A6. Conclusion

The hydrologic methods and simulations used as part of this study determined that denitrification rates were 0.0016 day^{-1}, which yielded denitrification rates of 24 - 40% in La Pine. Based on the denitrification rates found in this study, assumptions made in previous studies of a 25% reduction in nitrate are reasonable (Morgan et al., 2007).

While this study fills in the NOWTS data gap for vadose zone nitrogen transport, there is still a gap in understanding how contamination in vadose zone waters can be transferred to nitrate concentrations in well water. This has been touched upon but not studied in depth in La Pine (Hinkle et al., 2005).

Though vadose zone assumptions are reasonable, other limitations must be overcome in order for model predictions to satisfy stakeholders. As seen in the real estate transaction data, the majority of wells had nitrate concentrations of ≤1 mg/L. Nitrate concentrations peaked at a few locations, but concentrations varied across the landscape, suggesting that elevated nitrate concentrations from septic systems are localized. As seen in previous studies and SWAT modeling for this dissertation, although watershed-scale models do not have the resolution to accurately predict nitrate concentrations in specific wells, they can be accurate when looking at larger scales.

Soil samples taken in the La Pine area revealed a nitrate peak of 28 mg/L at the RES site, though all other soil samples were below 1.2 mg/L. The nitrate peak was likely not from a septic system but from a different man-made nitrate source.

Future soil studies can be improved by focusing on nitrate testing, since the other types of testing were less important for interpretation of the results. Soil studies can also be conducted by using two locations on the same property, one within 10 ft of a leach field and one >20 ft away from a leach field. This design would have a higher probability of testing soils which have been impacted by septic systems and would thus minimize the need for permits or permission for drilling.

A7. References

Albany County Planner, 2011, Casper Aquifer Protection Plan: Albany County, Wyoming, 132 p.

Amâncio, S., and Stulen, I. (Eds.), 2004, Nitrogen acquisition and assimilation in higher plants: Dordrecht ; Boston, Kluwer Academic Publishers, Plant ecophysiology v. 3, 298 p.

Bedient, P., Rifai, H.S., and Newell, C., 1997, Ground Water Contamination: Transport and Remediation: Upper Saddle River, NJ, Prentice Hall PTR, 603 p.

Carsel, R.F., 1996, Assessing Nitrogen Leaching in Unsaturated Media from Septic Tank Waste for the North Animas Valley, La Plata County, Colorado: US EPA, Nation al Exposure Research Laboratory, Ecosystems Research Division A Wellhead Protection Screening Assessment and Planning Document, 59 p.

Cole, D.R., 2006, Groundwater Quality Report for the Deschutes Basin, Oregon: Oregon Department of Environmental Quality, 59 p.

Deschutes County, 2009, SE1/4 SEC. 24 T21S. R10E. WM Deschutes County.:

Fan, J., Hao, M., and Malhi, S.S., 2010, Accumulation of nitrate N in the soil profile and its implications for the environment under dryland agriculture in northern China: A review: Canadian Journal of Soil Science, v. 90, p. 429–440, doi:10.4141/CJSS09105.

Gannet, M.W., and Lite, K.E., 2004, Simulation of Regional Ground-Water Flow in the Upper Deschutes Basin, Oregon: US Geological Survey Water-Resources Investigations Report Water-Resources Investigations Report 03-4195, 95 p.

Gannett, M.W., Lite, K.E., Morgan, D.S., and Collins, C.A., 2001, Ground-Water Hydrology of the Upper Deschutes Basin, Oregon: US Geological Survey, Oregon Water Resources Department, Cities of Bend, Redmond, Sisters, Deschutes and Jefferson Counties, The Confederated Tribes of the Warm Springs Reservation of Oregon, US EPA Water Resources Investigations Report 00–4162, 72 p., https://apps.wrd.state.or.us/apps/planning/owsci/view_project_image.aspx?project_type=GW&related_document_id=31 (accessed March 2019).

Grady, C.L.P., Daigger, G.T., Love, N.G., and Filipe, C.D.M., 2011, Biological Wastewater Treatment: CRC Press, 1022 p.

Hanson, B.R., Šimůnek, J., and Hopmans, J.W., 2006, Evaluation of urea–ammonium–nitrate fertigation with drip irrigation using numerical modeling: Agricultural Water Management, v. 86, p. 102–113, doi:10.1016/j.agwat.2006.06.013.

van der Heijde, P.K.M., 1994, Identification and Compilation of Unsaturated/Vadose Zone Models: US EPA EPA/600/SR-94/028, 8 p.

Hinkle, S., Bohlke, J., and Fisher, L., 2008, Mass balance and isotope effects during nitrogen transport through septic tank systems with packed-bed (sand) filters: Science of The Total Environment, v. 407, p. 324–332, doi:10.1016/j.scitotenv.2008.08.036.

Hinkle, S.R., Morgan, D.S., Orzol, L.L., and Polette, D.J., 2007, Ground Water Redox Zonation near La Pine, Oregon: Relation to River Position within the Aquifer-Riparian Zone Continuum: US Geological Survey, Deschutes County Scientific Investigations Report 2007–5239, 38 p.

Hinkle, S.R., Weick, R.J., Johnson, J., Cahill, J.D., Smith, S.G., and Rich, B., 2005, Organic Wastewater Compounds, Pharmaceuticals, and Coliphage in Ground Water Receiving Discharge from Onsite Wastewater Treatment Systems near La Pine, Oregon: Occurrence and Implications for Transport.: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Environmental Health Division Scientific Investigations Report 2005–5055, 98 p.

Hofstra, N., and Bouwman, A.F., 2005, Denitrification in Agricultural Soils: Summarizing Published Data and Estimating Global Annual Rates: Nutrient Cycling in Agroecosystems, v. 72, p. 267–278, doi:10.1007/s10705-005-3109-y.

Horton, K.W., 1958, Rooting Habits of Lodgepole Pine: Canada Department of Northern Affairs and National Resources, Forestry Branch Forest Research Division Technical Note No. 67, 26 p.

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Izbicki, J.A., Flint, A.L., O'Leary, D.R., Nishikawa, T., Martin, P., Johnson, R.D., and Clark, D.A., 2015, Storage and mobilization of natural and septic nitrate in thick unsaturated zones, California: Journal of Hydrology, v. 524, p. 147–165, doi:10.1016/j.jhydrol.2015.02.005.

L'Hirondel, J., and L'Hirondel, J.L., 2001, The case against nitrate: a critical examination, *in* L'Hirondel, J. and L'Hirondel, J.L. eds., Nitrate and man: toxic, harmless or beneficial?, Wallingford, CABI, p. 35–68, doi:10.1079/9780851995663.0035.

MacLeod, N.S., and Sammel, E.A., 1982, Newberry volcano, Oregon: A Cascade Range geothermal prospect: Oregon Geology; Oregon Department of Geology and Mineral Industries, v. 44, p. 123–131.

Madison, R.J., and Brunett, J.O., 1984, Overview of occurrence of nitrate in groundwater of the United States, *in* National Water Summary 1984 - Hydrologic Events, Selected Water-Quality Trends and Ground-water Resources., US Geological Survey, Water-Supply Paper 2275, p. 93–105.

McLaren, A.D., 1976, Rate constants for nitrification and denitrification in soils: Radiation and Environmental Biophysics, v. 13, p. 43–48.

Moradzadeh, M., Moazed, H., Sayyad, G., and Khaledian, M., 2014, Transport of nitrate and ammonium ions in a sandy loam soil treated with potassium zeolite – Evaluating equilibrium and non-equilibrium equations: Acta Ecologica Sinica, v. 34, p. 342–350, doi:10.1016/j.chnaes.2014.09.002.

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

National Climatic Data Center (NCDC), 2019, Climate Data Online (CDO):, https://www.ncdc.noaa.gov/cdo-web/search (accessed September 2019).

Oregon Department of Environmental Quality (ODEQ), 2018a, OAR 340-071-0800 Tables.

Oregon Department of Environmental Quality (ODEQ), 2018b, State of Oregon: Residential - Rules and Regulations For Onsite Wastewater Treatment Systems:, https://www.oregon.gov/deq/Residential/Pages/Onsite-Rules.aspx (accessed December 2018).

Oregon State University – Central Analytical Lab (OSU CAL), 2017, Standard Operating Procedures 2017:

Panagopoulos, I., Mimikou, M., and Kapetanaki, M., 2007, Estimation of nitrogen and phosphorus losses to surface water and groundwater through the implementation of the SWAT model for Norwegian soils: Journal of Soils and Sediments, v. 7, p. 223–231, doi:10.1065/jss2007.04.219.

Pankratz, A., 2000, Deschutes County: Septic Tank Permit Application: Deschutes County Septic Tank Permit Application 211024D001100EH20001116999001, 10 p.

Rainwater, K., and Jackson, A., 2004, Evaluation of Drainfield Absorption and Evapotranspiration Capacity: Texas On-Site Wastewater Treatment Research Council, 73 p., https://www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/PhaseII-Report.pdf (accessed January 2019).

Rayne, T.W., Bradbury, K.R., and Krause, J.J., 2018, Impacts of a Rural Subdivision on Groundwater Quality: Results of Long-Term Monitoring: T.W. Rayne et al.: Groundwater, p. 13, doi:10.1111/gwat.12666.

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rolston, D.E., Fogg, G.E., Decker, D.L., Louie, D.T., and Grismer, M.E., 1996, Nitrogen isotope ratios identify nitrate contamination sources: California Agriculture, v. 50, p. 32–36, doi:10.3733/ca.v050n02p32.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Schlesinger, W.H., and Bernhardt, E.S., 2013, Biogeochemistry: An Analysis of Global Change: Elsevier, Academic Press, 672 p.

Selker, J.S., Keller, C.K., and McCord, J.T., 1999, Vadose Zone Processes: CRC Press, 352 p.

Spurr, K., 2017, State kills $17M Wickiup Junction project: The Bulletin 19 October, Bend, Oregon, http://www.bendbulletin.com/localstate/5683944-151/state-kills-17m-wickiup-junction-project (accessed March 2019).

Tillotson, W.R., Robbins, C.W., Wagenet, R.J., and Hanks, R.J., 1980, Soil Water, Solute and Plant Growth Simulation: Utah Agricultural Experiment Station, v. Bulletin 502, p. 52.

US Bureau of Reclamation (USBR), 2017, Wickiup Dam:, https://www.usbr.gov/projects/index.php?id=91 (accessed February 2017).

US Department of Agriculture (USDA), 2018a, Estimating Moist Bulk Density by texture: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_074844 (accessed January 2018).

US Department of Agriculture (USDA), 2018b, Web Soil Survey-Soil Data Explorer:, https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed January 2018).

US Naval Observatory (USNO), 2015, Duration of Daylight/Darkness for One Year: USNO:, http://aa.usno.navy.mil/data/docs/Dur_OneYear.php (accessed January 2018).

Watershed Professionals Network, 2002, Little Deschutes River Subbasin Assessment: Upper Deschutes Watershed Council.

Weaver, C., 2014, Effectiveness of Suction Lysimeters in Determining Contaminant Transport Within Leaching Bed Systems: University of Guelph.

Wenck Associates, 2019, Albany County Septic System Impact Analysis: Wenck Associates, Albany County, Wyoming Department of Environmental Quality, 269 p.

Winchell, M., Srinivasan, R., Luzio, M.D., and Arnold, J., 2013, ARCSWAT INTERFACE FOR SWAT2012 USER'S GUIDE:

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

Yeh, H.S., and Wills, G.B., 1970, Diffusion coefficient of sodium nitrate in aqueous solution at 25.deg. as a function of concentration from 0.1 to 1.0M: Journal of Chemical & Engineering Data, v. 15, p. 187–189, doi:10.1021/je60044a025.

Appendix B

Setting and History of Conflicts over Nitrates from Septic Systems:

La Pine, OR and Laramie, WY

B1. Introduction

In the communities of La Pine, OR from the 1950s to the 1970s, residential subdivisions expanded outside of city limits into rural areas (Watershed Professionals Network, 2002). For many of these residences, the only source of potable water was groundwater and the only way to dispose of wastewater was septic systems or other onsite wastewater treatment systems (OWTS). Wastewater from septic systems can contaminate groundwater (used as a water source) if it is not fully treated.

Many of the rural homes were constructed before environmental and health regulations were put in place (e.g., Safe Drinking Water Act 1974 and Wellhead Protection 1986). Some of the water infrastructure for residences built from the 1950s to the 1970s was poorly constructed by the standards of the time of this study, or else systems had not been maintained, increasing the potential for groundwater contamination (City of Laramie, 2010).

One of the wastewater contaminants of concern from OWTS is nitrate. Nitrate contamination of groundwater was identified as an environmental and human health issue in 1945 when methemoglobinemia in infants was attributed to nitrate from well water (Comly, 1945). Nitrate can also cause algal blooms in surface waters.

Nitrates from onsite wastewater treatment systems (NOWTS) have been an area of conflict in La Pine, OR and Laramie, WY for decades. The purpose of this study is to determine how the history and setting of the NOWTS conflicts in La Pine and Laramie affected the stakeholders involved in these conflicts.

The general setting of a conflict includes geography, laws, personal relationships, urban-rural divide, culture, levels of expertise, power disparities, and communication. The history is the changes in the conflict over time: stakeholder understanding of NOWTS, opinions based on past experience, emotional responses, fatigue, and successor efforts.

In this study, *stakeholders* included anyone who had an interest or concern in the NOWTS conflicts in La Pine and Laramie—including residents, governments, and experts and other groups.

B2. Literature Review

B2.1 Regional Overview of Nitrate in Groundwater in the Western US

Though NOWTS is a widespread issue, there are few statistics on either nitrate contamination in private wells or the health impacts of nitrate. Statistics are lacking because:

- Private wells are not regulated for water quality in most areas, and testing is at the consent of well owners.
- The symptoms of methemoglobinemia can be difficult to identify and elevated nitrates have little impact on older people.
- The impact of nitrates is often seen as a localized community issue.

An estimated 13,000,000 homes rely on well water in the US, based on the US Census American Housing Survey 2015, and 33% of the potable water in the US comes from groundwater. One estimate suggested that 20% of wells in agricultural areas and 3% of wells in urban areas had nitrate concentrations over 10 mg/L (Burow et al., 2010).

In the Western US, 51 communities have been identified as having issues with NOWTS (Fig. B1). However, there is no clear delineation between NOWTS issues and other nitrate contamination issues. In some of the communities NOWTS contributed to a small portion of the total nitrate contaminant load. These communities were included because there were studies, regulations, litigation, and other activities based on NOWTS.

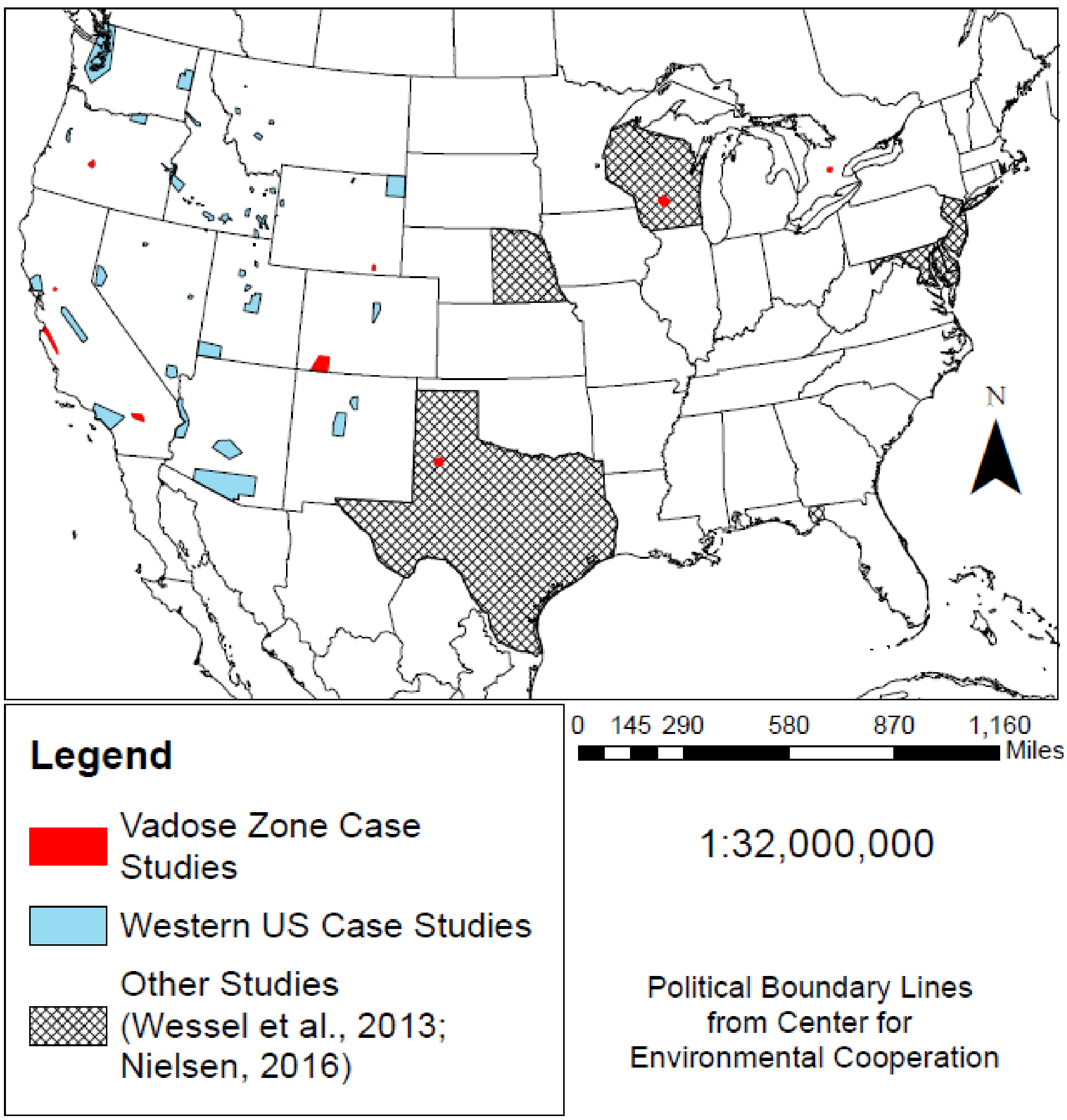


Fig. B1. Map of NOWTS Communities

The NOWTS communities depicted in Fig. B1 were determined using journal articles, US Geological Survey (USGS) reports, agency reports, reports from consulting firms, plans (from counties, cities, states, agencies, and NGOs), monitoring reports, local newspaper articles, websites, agency guides, manuals, administrative rules, laws, patents, and graduate theses. There were two previous collections of NOWTS-related case studies (Wessel et al., 2013; Nielsen, 2016).

B2.2 Overview of Governance and Management Approaches to NOWTS

In NOWTS communities, a variety of approaches have been undertaken to address NOWTS issues. Governments use regulatory approaches to direct or restrict the activities of a regulated group based on laws. Non-regulatory approaches do not require government actions, though governments can use non-regulatory approaches. Non-regulatory approaches often attempt to incentivize certain activities, since the groups involved often do not have the ability to enforce restrictions.

Many communities have used a mix of both regulatory and non-regulatory approaches to address NOWTS. Other communities have used institutions that were a mix of governmental and non-governmental groups. Mixed approaches include public-private partnerships and collaborative governance. Public-private partnerships are arrangements between governments and groups which are not under government control (e.g., businesses or corporations). Collaborative governance is when two or more groups (government, experts, residents, and other stakeholders) pool power and resources between stakeholders for a common goal (O'Brien, 2012).

Table B1. Regulatory Approaches to NOWTS

Approach	Description
Laws	Laws and regulations which have been passed by a government body. Includes laws such as the Safe Drinking Water Act.
Water Rights/Quotas	Water rights and quotas place limits on the amount of water that can be withdrawn from an aquifer. Ex. In La Pine, all surface water rights were taken, so the only source of water for residents was groundwater. City of Laramie bought Monolith Ranch to obtain additional water rights.
Water Standards	Water standards are regulations to keep contaminants below a level in a water body, to minimize the health risk from a contaminant. Ex. Oregon has a reference level for nitrate in groundwater of 10 mg/L.
Litigation	Litigation involves legal action taken against another party. Ex. *Central Oregon LandWatch vs. Deschutes County and Oregon Department of Environmental Quality* (Ryan et al., 2016).
Ordinances	Ordinances are pieces of legislation passed by a county or municipal authority. Ex. Deschutes County passed an ordinance requiring the upgrade of septic systems in 2008, but the ordinance was overturned in a special election in 2009.
Land Use Planning/ Zoning	Government regulation and organization of the ways land can be used and developed. Agencies can also designate special areas that are off limits to specific types of land use. Ex. Many communities set minimum lot size for rural lots with OWTS.
Building Codes/ Construction Standards	Building codes and construction standards are regulations on the design of constructed objects. Ex. Deschutes County passed an ordinance in 2008 that required homes to be constructed with OWTS to treat nitrate.
Administrative Rules	Administrative rules are rules created by agencies, boards, or commissions to implement and interpret their authority. Ex. ODEQ follows OAR 340-071, which specifies septic system design.
Superfund	Superfund is an EPA program to clean up sites that have been contaminated with hazardous substances. Although no NOWTS case study has fallen under Superfund, Superfund has been considered for some areas.
Sole Source Aquifer Program	The Sole Source Aquifer Program is an EPA program that designates aquifers as the sole source of water for a community. Development over an aquifer with federal funds must receive EPA approval.
Agreements	Aquifers often cross political boundaries. Thus, agreements can be created between government agencies about how to address water issues. Ex. 201 Intergovernmental Agreement between Laramie and Albany County.
Areas	Areas are geographic locations where there is local concern over an issue. Ex. Deschutes County High Groundwater Areas, where development was discouraged on areas with shallow water tables.

Continued on next page.

Table B1. Regulatory Approaches to NOWTS *Continued*

Approach	Description
Plans, Goals and Guidelines	Plans, goals, and guidelines are statements by a group about their intentions. Ex. The Casper Aquifer Protection Plan (CAPP), which provided guidelines to protect the Casper Aquifer in Laramie, WY.
Working Group /Advisory Committee/ Watershed Council	Groups formed by governments or as grassroots organizations that often focus on a specific issue or location. Group members can be publicly elected or appointed by governments. The power of these groups varies from direct governance to an advisory role. Ex. ODEQ steering committee in La Pine and Technical Advisory Committee in Laramie.
Public Hearings	Public hearings are meetings in which the public can give testimony on a local issue or government action. Testimony is often summarized in a public record.
Infrastructure Projects	There are a wide variety of infrastructure projects used to address NOWTS. While projects may be created by a variety of entities, they require government approval. Ex. Sewers, water treatment plants, and ATT.

Table B2. Non-Regulatory Approaches to NOWTS

Approach	Description
Non-Governmental Organizations	Groups of stakeholders who work toward a specific cause. These groups are often local but can also be part of larger national or international networks. Ex. Deschutes County Citizen's Action Group (CAG) or CAP Network
Experts	Experts have authoritative knowledge of an area. Experts serve a variety of functions: conducting studies of an area, providing expert opinions for media and litigation, sharing information resources, or communicating knowledge to stakeholders. Expert levels fall on a spectrum – from professional scientists and engineers to stakeholders who may have decades of experience in conflicts.
Studies	Studies can be used to acquire more knowledge about conditions and to address stakeholder needs.
Resident Science	Science performed by experts and other stakeholders in their capacity as residents. Resident science is not funded or supported by a government or academic institution. Ex. In Laramie, the CAP Network collected nitrate samples from private wells, and a student completed an award-winning science fair project on nitrate from plants.
Mediation	Intervention in a conflict between parties of aquifer users. Mediators can be an outside third party or a committed community leader.
Education and Outreach	Education and outreach can be used to inform stakeholders about issues and to build common ground between stakeholders. Ex. Tabling, workshops, newsletters, and distribution of educational materials.
Grants	Resources provided by public or private parties to fund studies or projects.
Media	The media and press have access to many views and can disseminate information on aquifer issues. Ex. Local newspapers such as The Bulletin, Bend, or Laramie Boomerang.
Crisis	It often takes a large event to bring issues to the public's attention and to create the political will for action. Crisis events can also destroy previous institutions. New institutions can be constructed, including new ideas.

Table B3. Mixed Approaches

Approach	Description
Public-Private Partnership	Cooperative arrangements between government and groups that are not under direct government control (such as a company).
Collaborative Governance	Two or more groups that pool power and resources between groups towards a common goal.

B2.3 La Pine

This section gives a brief history of the conflicts in La Pine and more detailed information on the groups involved in the conflicts; their views are presented in the results and discussion sections.

The City of La Pine is located in Central Oregon, 28 miles south of Bend, OR. There were 1,653 residents in the City of La Pine in the 2010 US Census, with an estimated population of 1,777 by 2015. La Pine is a rural community with an estimated 18,000 residents in the City of La Pine and outlying areas (Morgan et al., 2007). Almost all residents of the La Pine Area use groundwater from wells, and the majority of residents are on septic systems.

According to the 2010 US Census, the average annual income in the City of La Pine was $25,848, and 76.4% of the population had high school diplomas or equivalent, with 3.8% having a bachelor’s degree or higher.

There are many part-time residents and tourists in the La Pine Area; it is estimated that in 1980, 46% of the residents were seasonal, and by 2000, 20% of the residents were seasonal (Morgan et al., 2007).

The La Pine area has a large retired population. This population includes retired technical experts connected to NOWTS issues: scientists, engineers, and employees of state agencies (Stollar, 2006; Gillette, 2007). There are also educated experts with doctoral degrees not related to NOWTS (Hofman, 2007; Huddle, 2012). Lastly, there are self-educated experts who have for decades either been involved in NOWTS policymaking, constructed and maintained wells or septic systems, or researched NOWTS on their own. For this study, these groups will be collectively referred to as resident experts, since they were residents of the community and became informed regarding NOWTS issues.

Groundwater quality has been an issue in La Pine since nitrate concentrations >10 mg/L were first found in groundwater wells in 1979 (Cole, 2006). Concern over nitrate grew, starting in the late 1990s and 2000s, due to the rapid population growth (54% from 1990 to 2000, according to the US Census) and development of Deschutes County.

Concern about NOWTS was the motivating factor for studies in the La Pine area by USGS (Gannet and Lite, 2004; Hinkle et al., 2005, 2007, 2008; Morgan et al., 2007), Deschutes County (Rich, 2005), and ODEQ (Cole, 2006). The USGS studies concluded that septic systems were the source of the nitrate (Rich, 2005; Morgan et al., 2007). Citizen scientists within the Deschutes County Citizen's Action Group (CAG) have disputed the nitrate contamination models and experimental procedures of the USGS studies (Huddle, 2012; Nigg and Baggett, 2013).

CAG is an NGO whose goals are "To preserve quality of life, protect individual and community rights, as well as to conserve rural identity and natural resources."

The NOWTS conflicts were highly contentious in 2008, when the Deschutes County Board of County Commissioners passed Ordinance 2008-012 and Resolution 2008-021, which required the use of OWTS that treated for nitrate. The ordinance and resolution were both rescinded in 2009 as a result of a special election and community opposition (Nigg and Baggett, 2013).

After the county Ordinance 2008-021 was rescinded in 2009, the ODEQ created a steering committee to find a viable solution to NOWTS, comprised of residents of the La Pine Area (Nigg and Baggett, 2013). One of the suggestions from the committee was to have an Oregon Land Use Planning Goal 11 exception to allow clustered water treatment outside city limits.

The Goal 11 exception was passed in 2015 but was remanded in 2016 by the Land Use Board of Appeals (LUBA) after *Central Oregon Landwatch (Petitioner), vs. Deschutes County (Respondent) and Oregon Department of Environmental Quality* (Ryan et al., 2016).

Central Oregon LandWatch is a group whose goals (paraphrased mission statement) are to balance conservation, natural resources and the environment with sustainable development, and to have all stakeholders equally share the costs and benefits of community development (Central Oregon LandWatch, 2019).

At the time of this study, permitting for OWTS was on a case-by-case basis by the Oregon Department of Environmental Quality (ODEQ) and Deschutes County. ODEQ and Deschutes County determined whether a construction project could use nitrate-treating OWTS or a conventional septic system (Deschutes County, 2019). Two OWTS have been approved for use in the La Pine Area: the Yugo Standard OWTS and the Orenco Style Alternative Treatment Technologies.

Table B4. History of La Pine

Year	Event
1910	Community of La Pine platted.
1930s	Construction of dams and reservoirs.
1950s	Mid-State Electric Cooperative and increase in tourism.
1950	Start of Oregon septic system regulations under the State Health Division.
1960s	Sunriver Resort established.
1966	Repeal of zoning laws, allowing for more development.
1973	ODEQ takes responsibility for regulating septic systems.
1974	Adoption of Oregon Land Use Goal 11(OAR 660-015-0000(11)).
1978-1979	La Pine Groundwater Quality Study: Oregon Department of Environmental Quality, 8 of 46 wells over 10 mg/L, highest 25.8 mg/L.
1982	La Pine Aquifer Management Plan: Century West Engineering Corporation: Nitrate levels stable, higher nitrate near areas with septic monitoring wells.
1983	Water Wonderland Sewage Treatment constructed.
1985	Attempt to incorporate the city of La Pine.
1986	Sewer constructed for La Pine Core Area with STEG (septic tank effluent gravity).
1989	ORS 448.271 – Real estate transaction well testing for arsenic, nitrate and coliform.
1993	La Pine Groundwater Study –4 of 36 domestic wells had nitrate concentrations over 10 mg/L, with a highest concentration of 16 mg/L.
1994-1995	La Pine Groundwater Quality and Modeling Study.
1996	Deschutes County receives Regional Problem Solving Grant.
	Transferable Development Credit – People with undeveloped lots get credits. Deschutes County bought credits if landowner promised not to develop, to allow more development in city of La Pine (New Neighborhood).
1997	Sewer Feasibility Study for the La Pine Area.
1998	Sewer was determined to be not feasible.
1999	La Pine On-Site Demonstration Project: Collaborative effort between USGS, ODEQ, and Deschutes County; $5.5 million from EPA.
2002	Transferable Development Credit Program: Sold land in 'New Neighborhood' to developers who must buy credits to develop.
2005	ODEQ amends state rule to allow counties to issue permits for nitrogen reducing systems for residences.
	ODEQ fines contractor for installing septic system without permit.

Continued on next page

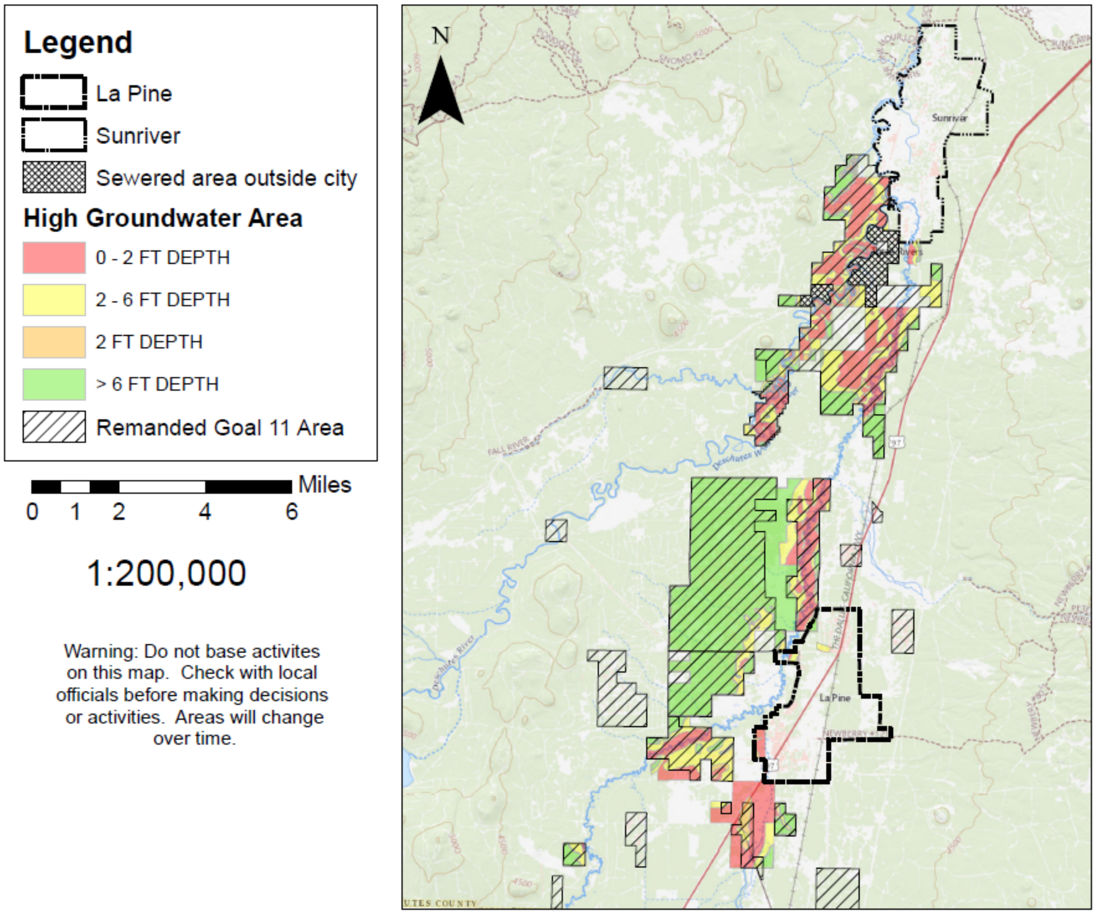
Table B4. History of La Pine *Continued*

Year	Event
2006	City of La Pine incorporated.
	Expansion of Water Wonderland service area.
	Resignation of three County Planning Commissioners who were connected to developers.
	Transferable Development Credit program updated to allow developers to gain credits by funding retrofitting septic systems with ATT or by paying into a 'Partnership Fund.'
2007	Lead up to 2008 county ordinance involving many meetings and groups to search for alternative solutions. Political activity included public meetings, editorials, formation of Deschutes County Groundwater Group, fake warning signs about well water quality.
2008	Deschutes County Ordinance requiring upgrading septic systems.
	CAG sues Deschutes County over ordinance.
2009	Special election overturns 2008 county ordinance requiring upgrades to septic.
	Meeting at high school between officials and residents about groundwater nitrate.
2010	ODEQ forms stakeholder steering committee.
2013	Recommendations from steering committee.
2014	Septic inspection and maintenance company dissolves and owner runs away.
2015	Goal 11 exception passed for most residences in the La Pine area.
	Crescent Sanitary District: Engineering Report of Wastewater System Improvement.
2016	Goal 11 exception remanded.
	Senate Bill 1563: ODEQ provides grants for low interest loans for septic installation maintenance repair.
	House Bill 4125: Failed to pass, would have required Oregon Health Authority to analyze groundwater contamination data and provide education to contaminated areas.
	City of La Pine, Oregon: Wastewater System Study Update, Water System Study Update.
2018	The City of La Pine received grants from federal and state governments to cover $22 million of $25 million needed for expansion of sewer in La Pine City limits.

(The Bulletin, 2005; Raff, 2006; Cole, 2006, 2006; Chu, 2007; The Bulletin, 2007; Borrud, 2010; Shorack, 2014; Pedersen, 2015; Bulletin Editorial Board, 2018) The ODEQ and County have both conducted periodic monitoring in the La Pine Area; not all times have been listed.

Table B5. Regulations in La Pine

Regulation	Details
Oregon Groundwater Protection Act 1989	Goal of the act is to prevent contamination, conserve, restore, and maintain groundwater resources. Gave Oregon Department of Environmental Quality (ODEQ) jurisdiction over groundwater.
Oregon Administrative Rules (OAR)	Specific interpretations of state laws by state agencies.
OAR 340-40	The reference level at which ODEQ would take action; for nitrate in groundwater, it was 10 mg/L.
OAR 340-071-0400	ODEQ has flexibility in the type of regulation used to address groundwater contamination.
OAR 340-071	Wastewater treatment systems not directly mentioned in regulation have to pass a testing process. System approval is based on which system provides best water treatment.
Oregon Revised Statute (ORS) 448.271	Required that wells be tested for arsenic, nitrate, and coliform bacteria by sellers after real estate transactions.
ORS 607.005	Created livestock districts, where it is unlawful for livestock to run at large: West La Pine, Lazy River Annexation, and Deschutes River Rec Homesites.
Oregon Senate Bill 100 (SB 100) 1973	Required land use planning by local governments and is legally binding.
Oregon Land Use Planning Goals	Oregon Statewide planning goals which land use plans are required to follow. Minimum size of rural lots is 10 acres.
Oregon Land Use Planning Goal 11	Sewer facilities cannot extend outside urban growth boundaries. Outside urban growth boundaries, wastewater cannot cross property lines.
Deschutes County High Groundwater Areas	More stringent regulation of areas where the water table is less than 24 inches below the ground surface.
Deschutes County Transferable Development Credit Program (TDC) Ordinance 2002-010, 2006-016	Credits are required to develop land in a "new neighborhood" in City of La Pine. Developers gain credits by buying easements to not develop land, helping landowners get ATT, or paying into a partnership fund.
Deschutes County ATT Funding Programs	Loans, rebates, subsidies, deferred costs until sale of the property. The distribution of funds in the past was often through the NGO NeighborImpact.



Service Layer Credits: USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed October 2018.

All layers except for the Goal 11 Exception area were provided by Deschutes County, either through direct contact, or from http://data.deschutes.org/.

The Goal 11 exception area was recreated from (Deschutes County, 2015, Goal 11 Exception: Exhibit A - Index Map to Ordinance 2015-007)

Fig. B2. La Pine Regulatory Landscape

B2.4 Laramie

This section gives a brief history of the conflicts in Laramie and more detailed information on the groups involved in the conflicts; their views are in the results and discussion sections.

The City of Laramie is located in southeastern Wyoming on the High Plains on the west side of the Laramie Range. According to the 2010 US Census, the City of Laramie had a population of 30,816. Albany County, the county in which Laramie is located, had a 2010 population of 36,299. Included in the census is the student population at the University of Wyoming (UW) of 13,657 in 2010.

The main water source for the City of Laramie is the Casper Aquifer, which provides approximately 60% of Laramie's water, with the rest coming from the Laramie River. The City of Laramie provides water for 95% of the residents in Albany County. The Casper Aquifer is the only source of water for residents of subdivisions to the east of Laramie who are on private wells (WHPA, 2008).

The City of Laramie and Albany County started taking action on groundwater quality based on the 1986 EPA amendment to the Safe Drinking Water Act (SWDA), which included wellhead protection and started enforcement measures in 1990. During the 1990s, the City of Laramie created a Wellhead Protection Plan and a Wellhead Protection Ordinance to protect the City of Laramie's water supply and to comply with SDWA.

In 1995, a City of Laramie consultant indicated that the OWTS for a proposed veterinary clinic, which was outside of Wellhead Protection Area, posed a risk to the Casper Aquifer due to the clinic's proximity to the concealed Sherman Hills Fault. The veterinary clinic was eventually approved and constructed.

In 1998, the EAC formed a Technical Advisory Committee to delineate a more comprehensive aquifer protection area (the Casper Aquifer Protection Area or CAPA) and created the Casper Aquifer Protection Plan (CAPP).

The Environmental Advisory Committee (EAC) was formed by seven people jointly appointed by the Laramie City Council and the Albany County Board of Commissioners. The EAC serves an advisory role for both the Laramie City Council and the Albany County Commissioners.

The EAC Technical Advisory Committee was composed of local engineers, geologists, water professionals, and landowners of large parcels of land located within the known aquifer area (Jarvis, 2014). It was possible to create a Technical Advisory Committee in Albany County because there were numerous water engineers, geologists, and hydrologists, many of them affiliated with UW, Wyoming Geological Survey, and the community of local water consultants.

In Albany County, many groups have been affiliated at some point with Groundwater Guardian, including the City of Laramie, EAC, Albany County, and the Casper Aquifer Protection (CAP) Network. Groundwater Guardian is a national program run by the Groundwater Foundation, which "provides recognition, resources, connection to other groups, education and training for groups advocating the protection of groundwater."

The CAPP was approved by the Wyoming Department of Environmental Quality (WDEQ) in 2002 and served both the City of Laramie and Albany County. The purpose of the CAPP was "to reduce the possibility of contamination to the

Casper Aquifer" (WHPA, 2008). The CAPA was the area covered by the CAPP. The CAPA extends to the east of Laramie, with 97% of it outside of Laramie city limits. The two largest landowners in the CAPA are Warren Livestock LLC and the Mountain Cement Company. The next largest landowners are the Bureau of Land Management, UW, and State of Wyoming. There are many small landowners in the western part of the CAPA; most are residential landowners.

Land use plans are not legally binding documents in Wyoming; instead, they serve as voluntary guidance documents. Plans can also be used as evidence of due diligence or public need in court (Mandelker, 1976). The CAPP became legally binding when it was used as the basis for Laramie City Ordinance 1404 in 2002.

In 2006, the CAPP was enforced by the City of Laramie when UW proposed expanding its golf course. The golf course expansion was opposed by some residents as well as by the Citizens for Open Space and Outdoor Recreation. Due to the conflict over the golf course expansion, the city placed a moratorium on development and started the process of revising the CAPP. The developers of the golf course expansion briefly considered litigation against Laramie over the moratorium on development.

In 2007, Wittman Hydro Planning Associates Inc. (WHPA), a water resources consulting firm, was hired by the City of Laramie to update the CAPP. The updated CAPP was adopted by the City of Laramie in 2008 (WHPA, 2008). The 2008 CAPP was controversial in the Laramie area. The more controversial parts of the CAPP were the recommendation to connect private well owners east of Laramie to sewer systems and the recommended changes to the western boundary of the CAPA. Another controversial aspect was that the 2008 CAPP was created by an outside consultant instead of by local stakeholders, as the previous CAPP had been (Starkey, 2008). There was also conflict over whether WHPA was qualified to revise the CAPP, since WHPA did not have a geologist on staff. The conflict reached the Wyoming Board of Professional Geologists, who determined that WHPA was practicing geology without a license.

The City of Laramie accepted the 2008 CAPP and used it to revise City Ordinance 1748A. Albany County chose not to follow the 2008 CAPP and created a separate CAPP in 2011 (Albany County Planner, 2011). In 2011, Albany County proposed a zoning regulation based on the 2011 CAPP, but the regulation was not passed until 2012 after a series of public meetings and compromises made to the regulation (LeClair, 2012).

Due to conflicts over the CAPP from 2008 to 2012, the Casper Aquifer was part of the public consciousness, as illustrated by activities like science panels (Haderlie, 2010), the formation of Albany County Clean Water Advocates (ACCWA) in 2007 (ACCWA, 2019), and the CAP Network joining the Groundwater Federation in 2010 (Groundwater Foundation, 2017).

The ACCWA, formerly known as Citizens for Clean Water (ACCWA, 2019), was a community group whose goal was to protect drinking water supplies (including the Casper Aquifer), promote data transparency, oppose loosening zoning and reducing prohibited activities on the aquifer, promote development in areas outside the CAPA instead of within the CAPA, and encourage development in the CAPA to use best practices to protect groundwater. ACCWA activities include: testifying and advocating at public meetings, public outreach, and education.

The CAP Network is a group supporting the protection of the Casper Aquifer and the protection of property rights. CAP Network activities include testifying and advocating at government meetings, outreach, education through a series of newsletters, and groundwater sampling in the CAPA. The CAP Network is composed of private well owners who live in or near the CAPA (Groundwater Foundation, 2017).

The ACCWA and CAP Network are sometimes in opposition since the ACCWA's interests and values align with the City of Laramie, whereas the CAP Network's interests and values align with Albany County. Both groups have members who are technical experts—engineers, geologists, water professionals, water consultants, and faculty from UW.

After the update to the CAPA in 2008, a series of groups began to study the Casper Aquifer (Table B6).

Table B6. Casper Aquifer Studies

Group	Study	Details
Albany County	Albany County, Wyoming: I-80 Telephone Canyon: Casper Aquifer Protection Study (Athey, 2011)	Study of potential spill control options on Interstate 80.
Albany County	Interstate 80 spill controls	Spill control effort was stopped because landowners did not give permission to build spill control infrastructure (Tippin, 2014).
Albany County	Albany County Septic System Impact Analysis (Wenck Associates, 2019)	Study of pore water and soil in vadose zone beneath a septic system.
City of Laramie	Well Testing (City of Laramie, 2010)	Tested wells in subdivisions east of Laramie for nitrate in 2009 and 2010.
City of Laramie	East of Laramie Wastewater Feasibility Study (Schroeder et al., 2013)	Although septic systems did not pose risk to city water, a few rural wells in subdivisions were over 10 mg/L. Studied feasibility of clustered systems and connection to sewer.
City of Laramie	Laramie Monitoring Well Project (Hinckley and Moody, 2015)	Monitoring wells were placed near subdivisions east of Laramie. Nitrate and hydraulic characteristics were measured.
CAP Network	The CAP Network Groundwater Sampling Program (Starkey, 2017)	Quarterly and then annual testing of wells in subdivisions east of Laramie after 2011.
Student Plant Study	Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates! (Rovani, 2012)	Analyzed background nitrate concentrations in CAPA springs and soils.
UW	Many studies on aspects of the Casper Aquifer.	(Tippin, 2013b; Mast, 2016)
Oregon State University	Caffeine study of CAPA.	Caffeine levels were blow detection

In 2012, the City of Laramie refused permission for a car dealership in the CAPA area within city limits to expand its show room because car dealerships were on the list of activities prohibited in the CAPA. The car dealership had previously been grandfathered in because it was built during the 1960s, before the CAPP was created (Newman, 2012)

In 2015, a proposal was made for the creation of the Mountain West Estates Subdivision within the CAPA area. This subdivision occurs within the 1 mile radius outside of city limits where city and county concurrence was needed (Funk, 2015).

The Mountain West proposal was rewritten and proposed three times, and the developer had begun legal action against the City of Laramie. Mountain West received approval in 2016, but a concession was made to the city to use OWTS that treated for nitrate (Funk, 2016b).

In 2016, the City of Laramie did not approve the construction of a car dealership on Grand Avenue within Laramie city limits and the CAPA, also denying an associated proposed change to the prohibited activities in the CAPA. Letters and petitions from the public were written in opposition to changing the prohibited uses, since there were other areas around Laramie but not in the CAPA that could be developed (Fredregill, 2017). The rationales offered by the representatives of the car dealership for the change were that the car dealership would be connected to city water and sewer and have modern storage and disposal methods for hazardous waste from the car dealership, which would decrease the contamination risk to the aquifer (Funk, 2016a).

State laws shifted the extra jurisdictional boundaries (areas outside city limits where the cities have limited control), referred to locally as the “donut.” The donut was controversial because it allowed the City of Laramie government to regulate areas outside of the city. Residents of the donut felt that they were not represented by the regulations, because they could not vote or hold positions in city government. In 2013, House Bill (HB) 85 was passed by the state legislature. This bill reduced the extra jurisdictional area (where the city was able to enforce health-related quarantine notices and regulations) from five (5) miles to a half (½) mile outside the city limits.

Furthermore, city ordinances extending outside city limits could be nullified by county regulations.

In 2018, HB 14 was passed, changing the extra jurisdictional area so that city health-based regulations did not apply to unincorporated areas if a county plan was in place, although counties could delegate regulations to cities. Subdivision creation development within one (1) mile of city limits required only county approval if a comprehensive plan was in place, and if a plan was not in place, both city and county approval were required. A similar bill was proposed at the time but did not pass (HB 13) that would have made it more difficult for cities to annex areas. The bill also would have changed rules on plat development and subdivisions within one (1) mile from requiring both city and county approval to only needing county approval.

Although the CAPP was not the direct cause of HB 85 and 14, the CAPA was part of a series of similar conflicts between cities and counties in Wyoming which led to the creation of these bills. In Albany County, some of the conflicts that were not related to the CAPP included disposal of garbage for residents outside of city limits (Tippin, 2013a) and the Laramie City Parks and Recreation Master Plan (Mast, 2014).

Starting in 2011, there have been a series of efforts to buy some of the land owned by large nonresidential landowners in the CAPA and convert it into undeveloped public land. The first effort in 2011, was a proposed land swap between Y Cross Ranch, UW, and Colorado State University. The proposal fell through when it was determined to conflict with the agreement between UW and the donor of the land. The land swap was followed by a proposal to the state legislature to have the state buy the land, but the proposal failed when it was not seconded by the State Senate Minerals Business and Economic Development Committee (Neary, 2012).

In 2017, Warren Livestock proposed to sell 5,500 acres of the CAPA land to Albany County for $14,000,000 (Baumann et al., 2017). Since Albany County did not have the funds to pay for the land, the Pilot Hill Committee was formed by stakeholders representing state and county governments, UW, and members of the community. At the time of this dissertation, the Pilot Hill Committee was raising funds to buy the land (Pilot Hill Project, 2019), and another land swap had been proposed to the state legislature.

In 2019, the conflict flared up again over upgrades to the Tumbleweed Express Gas Station outside of city limits, which had been in place since the 1960s. The conflict over the development was complex. The main reason the development was controversial was the potential for the gas station and associated businesses to contaminate the aquifer. Other reasons included a proposed change to land use regulations during the time period, the question of whether the Satanka Shale was thick enough to place it within or outside the CAPA, and the past permitting history of the gas station (Bendtsen, 2019a).

Table B7. History of Laramie

Year	Event
1868	Union Pacific Railroad surveyors lay out Laramie streets and lots. Laramie was a stop for steam trains to get water.
1934	Pope Springs runs dry.
1930s	City of Laramie starts getting water from the Laramie River.
1937-1940	City of Laramie builds municipal wells near Pope Springs.
1947	Untreated Laramie River water is used for trains and irrigation.
1950s	Trains start using diesel, thus no longer needing water for steam. Deal is established to allow Laramie to use the water no longer used by trains.
1953	Filtration plant built to treat water from Laramie River.
1967-1969	Annexation of West Laramie due to unsanitary shallow groundwater from septic and wells.
1960s	Subdivision development begins east of Laramie.
1970s	UW begins studying the hydrogeology of Laramie.
1975	Wyoming Real Estate Subdivision Act.
1978	UW student Don Lundy finishes his thesis on the Casper Aquifer.
1980s	City of Laramie builds municipal wells.
	The EAC is established.
1981	Monolith Ranch is purchased by Laramie to gain more water rights.
1986	EPA amends the Safe Drinking Water Act for Wellhead Protection.
1990s	Technical Committee formed to start creation of the CAPA.
1990	Wellhead Protection is first enforced.
1991	Casper Aquifer Wellhead Protection Plan is created.
1992	South of Laramie Water and Sewer District is created.
1993	City of Laramie receives EPA grants. Local consultant delineates Well Head Protection Plan.
1995	Veterinary Clinic built on Satanka Shale above Casper Aquifer.
1996	Draft Wellhead Protection Ordinance developed.
	Citizen comments suggest peer-review of WHPP.
1997	Laramie City Council and Albany County Commissioners task the EAC with developing an Aquifer Protection Plan with community volunteers.
	The 201 Intergovernmental Area is created.
1998	Nine Mile Water and Sewer District is created.
	EAC appoints volunteer committee.
	Technical Advisory Committee composed of engineers, geologists, hydrogeologists, and large acreage landowners completes CAPA delineation.

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Table B7. History of Laramie *Continued*

Year	Event
2000s	Growth of antidevelopment sentiment on CAPA, as development increased.
	Planning Commission split to County and City.
	EAC concerned about traffic and development near Aquifer.
2000	Albany County Commissioners and Laramie City Council sign a resolution supporting EAC development of the Aquifer Area Management Plan.
	City of Laramie designated a Groundwater Guardian Community by the Groundwater Foundation.
2002	Casper Aquifer Wellhead Protection Plan is created.
	WDEQ reviews CAPP.
	City of Laramie adopts Aquifer Protection Overlay (APO) Zone Ordinance and Albany county adopts APO Zone resolution.
	City of Laramie hires water outreach coordinator.
2006	WDEQ completes review of CAPP.
	University of Wyoming Jacoby Golf Course proposes expansion of an adjacent subdivision development. Citizen Petition opposes expansion on basis of proximity to water sources, pesticide/herbicide/fertilizer use, and CAPP.
	Citizens for Open Space and Outdoor Recreation files petition opposing development.
	EAC recommends denying annexation and permit for development based on nitrate loading study. Laramie drafts a comprehensive plan expressing desire to preserve open space and protect ridgelines from development.
	Building moratorium imposed until a modified Aquifer Protection Plan and associated ordinance (requiring environmental reports for new development in APO Zone) are adopted.
	City Council authorizes update of CAPP.
2007	Laramie City Groundwater Guardian designation lapses.
	Wittman Hydro hired by City of Laramie to updated CAPP.
	Lawyers for large landowners correspond with city council about legal "takings," lack of new scientific data, goals of citizen petitions, and extraterritorial jurisdiction.
	City Council authorizes submitting revised CAPP to WDEQ.
	Building moratorium extended to one year.
	WDEQ approves revised CAPP.
	Albany County Clean Water Advocates (Citizens for Clean Water) formed.
2008	City's consultant submits updated CAPP, overlay zone, and revised ordinance.
	City and County split on CAPA and CAPP.
	City's consultant submits estimate of Casper Aquifer recharge study. Estimate average annual recharge of approximately 1 inch for the last 26 years and a long-term trend of decreasing recharge.
	Citizens contact Wyoming Board of Professional Geologists (WBPG) regarding unlicensed practice by city's consultant, Wittman Hydro Planning Associates.

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Table B7. History of Laramie *Continued*

Year	Event
2008	City council adopts updated CAPP, overlay zone, a revised ordinance, and changes to western boundary of CAPA. CAPP is not certified by state-licensed geologist or engineer.
	Three local state-licensed geologists send letters of support to city's consultant after CAPP submitted to city.
	"Cease and desist" letter sent from WBPG to city's consultant.
2008-	Increased stakeholder awareness of Aquifer.
2009	Formal complaint regarding unlicensed practice of geology filed with WBPG by private citizen.
	Citizens for Clean Water lobby WBPG in support of city's consultant.
	City samples domestic wells in CAPA for N-nitrate.
	N-nitrate data reported for domestic wells sampled by private citizens.
2009	WBPG refers results of investigation to Albany County prosecuting attorney.
	County Planning and Zoning Commission begins updating CAPP.
	City begins monitoring nitrate in CAPA from residential wells.
2010	City budgets $1,000,000 for aquifer protection.
	City samples domestic wells in CAPA for N-nitrate.
	City retains a new consulting team to assess risk to city's well and spring from residential septic tanks. Risk assessed as "low."
	Citizens living in CAPA form CAP Network and join Groundwater Guardian.
	Science panel meets at University of Wyoming to discuss history, geography, and science of CAPP program.
2011	Albany County revises CAPP with WDEQ approval.
	Laramie River Conservation District buys abandoned Midwest Oil refinery site and begins remediation.
	CAP Network begins well water sampling program.
	City's Groundwater Guardian affiliation lapses.
	City hires new water resources specialist.
	City and county propose land swap of 50,000 acres at Y Cross Ranch with University of Wyoming Board of Trustees for 10,000 acres of land in and around CAPP.
	UW Foundation indicates swap is incompatible with agreement with Y Cross ranch and joint owner Colorado State University.
	Junior high student project on background levels of nitrate in Casper Aquifer. At Klein Spring, N-nitrate is 1.8 ppm (mg/L).
	Interstate 80 mitigation plan for spills is presented to city, county, and WDOT.
2012	Legislator proposes that State of Wyoming purchase 11,000 acres of land within CAPP for $15,000,000.
	Wyoming Water Development Office director pans land purchase concept in press.
	County Planning and Zoning Commission proposes changes to boundary of CAPP.
	Local geologist petition signed by property owners countering County Planning and Zoning Commission recommendation; petition filed with county commissioners.

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Table B7. History of Laramie *Continued*

Year	Event
2012	Citizens for Clean Water file petition with county commission and city council regarding flaws in county resolution.
	Junior high student completes continuation project exploring native nitrogen-fixing plants as a source of natural background level of nitrate in the Casper Aquifer. Confirms soils near naturally growing nitrogen-fixing plants such as mountain mahogany and cryptogamic crust produce elevated concentrations of nitrate as high as 200 ppm in water leached from soils.
	Water resources specialist resigns.
	Interstate 80 Aquifer protection Monitoring Well Plan and Detention Pond Design team selected.
	County commission approves regulations that differ from city's, specifically on maintaining western boundary defined in 2000.
	City of Laramie denies permit to expand car dealership show room on CAPA.
2013	HB 85 passes, repealing state law allowing city health regulations within 5 miles of city limits. Area reduced to ½ mile, and county can nullify regulations using ordinances.
	County commissioner suggests bill was in response to how Casper Aquifer was regulated.
	City hires new water resources specialist.
	East of Laramie Wastewater Study is created.
2014	Interstate 80 is unable to proceed due to inability to get land use permission from private landowner.
	Laramie Monitor Well Project is created.
2015	Proposed Mountain West Subdivision on CAPA.
	Phase II – Laramie Monitoring Well Project.
2017	Denial of Car Dealership Construction on CAPA.
	Bill 17LSO-0143 fails to pass, which would have required cities to have county approval of extra territorial ordinances.
	Warren Livestock brings forward a proposal for Albany County to buy CAPA land.
	Pilot Hill Project and Pilot Hill Committee formed by Albany County to find funding to buy CAPA Land.
2018	Proposed Specific Purpose Tax Laramie $250,000 for aquifer monitoring.
	Mountain West approved by Laramie with development changes.
	County funds Wenck Associates to study denitrification beneath a leach field.
	HB 13 proposed legislation on extra jurisdictional areas does not pass.
	HB 14 passes, so city health ordinances do not extend beyond city limits if county health plan exists. City approval is no longer required for developments within one mile of city limits if a plan is in place.
2019	Completion of Wenck study.
	90-day Albany County ban on CAPA development.
	ACCWA oppose Tumble Weed Express Gas Station.
2020	Tumble Weed Express Gas Station approved.

Updated from (Jarvis, 2014)

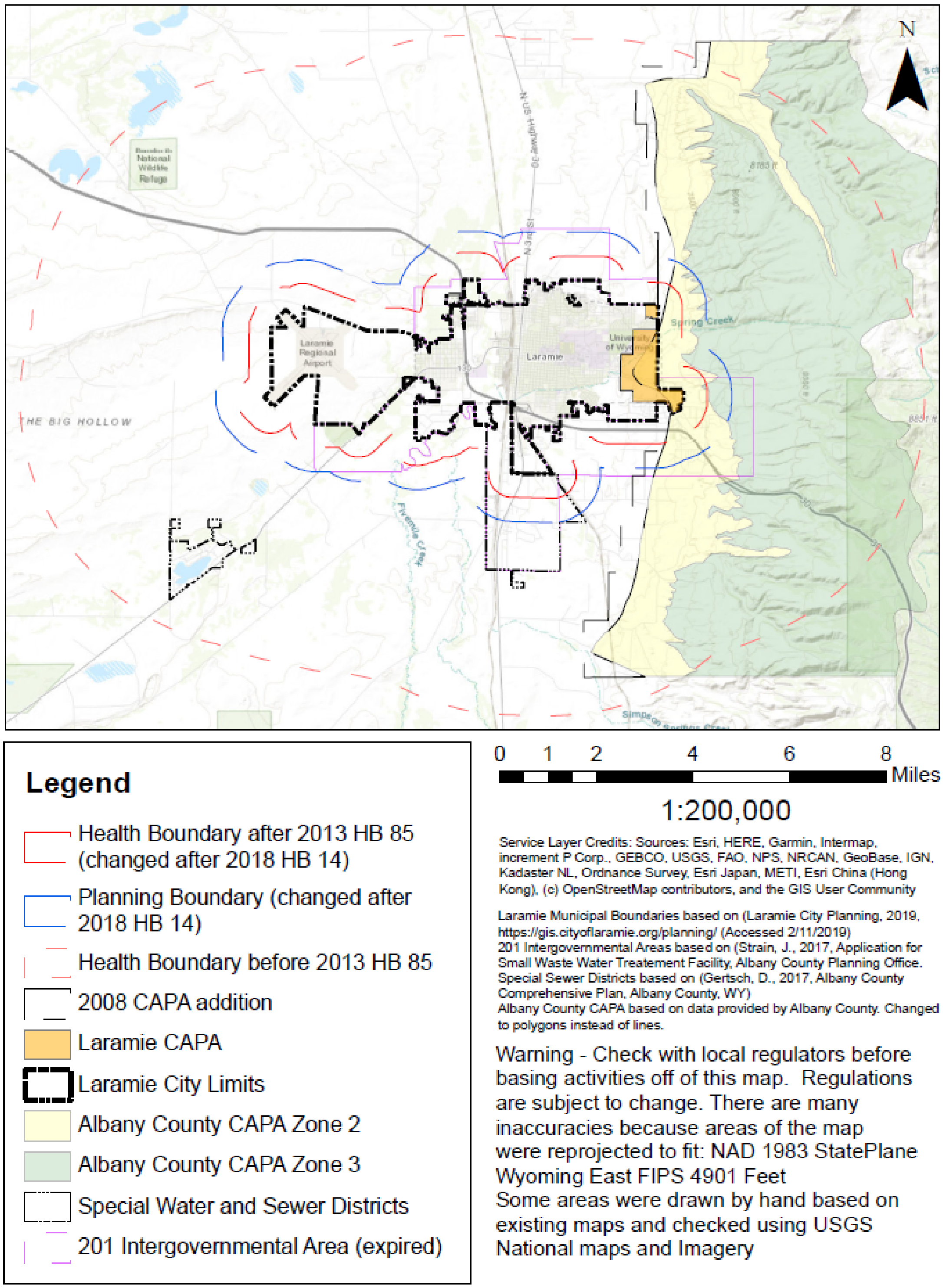

Fig. B3. Regulatory Landscape of Laramie, WY

B3. Methods

Two different methods were used to gather information in La Pine and Laramie. The first information-gathering effort was conducted concurrently with an environmental science investigation in La Pine (Appendix A). The goal of the effort was to have stakeholders participate in the environmental science investigation, so as to increase the legitimacy of the study. The second information-gathering effort was conducted in Laramie to build upon previous work in the area (Jarvis, 2014).

Funding and in-kind services for this project were provided by Central Oregon LandWatch, CAG, and CAP Network.

B3.1 La Pine: Survey Methods

Participants were recruited for the study by word of mouth through CAG, Central Oregon LandWatch, and individual community members. Fliers for the study were mailed to stakeholders in the Pinecrest Subdivision and neighboring ranches, as well as placed at the following establishments in the La Pine Area: CornerStore, Ray's Food Place, Ace Hardware, La Pine Senior Center, La Pine Clinic, La Pine Chamber of Commerce, Shop Smart, and La Pine City Hall. A notice was placed in "Wise Buys Ads & More," a local ads newspaper.

Any stakeholder in NOWTS conflicts in the La Pine Area was allowed to participate in the study. No compensation was given for participation in this study. The participants attended a series of activities, and it was expected that stakeholders participating in the study would not attend all study activities.

The first activity was a focus group held at the La Pine Senior Center on 8/18/2017. During the focus group, an explanation of the study was given in oral and written form, participants signed consent documents, and there was a discussion about NOWTS to determine stakeholder concerns.

A survey was created based on the focus group. The survey asked questions about: (1) participants' knowledge of the issue of groundwater nitrate contamination in the La Pine Area, (2) the importance of issues related to the groundwater nitrate issue, (3) attitudes about nitrate issues, (4) views of the study they were participating in as well as the "clarity" of the study.

The majority of the questions were placed on scales from one to five, and some questions had an option for "not applicable." The survey was created in paper and online using Qualtrix and hosted by Oregon State University.

The second activity was a meeting held at the La Pine Senior Center on 9/22/2017. Because there were many new attendees, the study explanation was reviewed again. An explanation was given about the risks of participation, as well as safety training. Associated materials were distributed with the explanations and trainings. The initial paper survey was not handed out because a majority of participants chose to take the survey online or at a later time.

For the third activity, participants aided the researcher in collecting soil samples in and near the Pinecrest/Holmes Acres Subdivision. Sample collection was conducted on a mix of days during the work week and weekend in October 2017. Sample collection was only conducted on days with clear, dry conditions to encourage the stakeholders to watch or participate in sample collection. One site was sampled on each day, and the expected participant time commitment for field work was four hours.

B3.2 Laramie: Interview Methods

The design of the interview methods and analysis for this study is based on methods used in previous studies (Jarvis, 2014).

The majority of the interviews were held over the week of the Fourth of July in Laramie. Participants were contacted two weeks ahead of time by email and asked whether they would be willing to participate in a 30-minute interview. Many participants were unable to schedule an interview time two weeks in advance, so they were contacted by email, by phone, or in person once the researcher arrived in Laramie. While in Laramie, some participants suggested other stakeholders who might wish to be interviewed; these leads were followed up, and some of the contacted stakeholders were willing to provide interviews.

Interviews were conducted in person or over the phone. All interviews were documented by hand in a notebook.

All participants were asked the following open-ended questions:

1. What is your connection to the Casper Aquifer?
2. Do you know the past 40 year history of issues surrounding the Casper Aquifer?
3. What issues relating to the issues surrounding the Casper Aquifer are most important to you, why?
4. What other groups or individuals are involved in issues surrounding the Casper Aquifer?
5. What is your desired outcome for the Casper Aquifer Protection process?
6. Do you have any additional thoughts you would like to share?
   *Follow-up questions were asked to clarify answers as needed.

An open-ended question format was chosen for interview flexibility. Participants were expected to have varying levels of knowledge about the Casper Aquifer, so follow-up questions could be tailored to participants. Open-ended questions were general and specific questions were avoided which could have been leading and may have biased results.

B3.3 Tools for Conflict Management

Conflict management tools are used in water conflict management and policy to unravel and organize information on the NOWTS conflicts in La Pine and Laramie. There is no one tool that can cover all situations or variables central to every water conflict. Conflict management tools were created to help frame and resolve conflict, but they are not a "panacea" for conflict (Ostrom, 1990; Emerson et al., 2012).

Three tools were used for this study: situation maps, the Circle of Conflict, and collaborative governance. Situation maps and the Circle of Conflict were used because they had been used previously in Jarvis (2014) to frame the conflict over nitrate contamination in the Casper Aquifer in Laramie. By continuing to use these tools, a standardized baseline of the conflicts was created, and the tools show how the conflicts have shifted over time.

Situation maps are a form of information mapping used to visually represent conflict. They consist of elements, which represent concepts or groups, which are connected by lines (or arrows) representing the relationships between elements. Situation maps have been used as part of collaborative learning for natural resource conflicts to promote systems thinking and to aid stakeholders in understanding where they and other stakeholder groups fit into natural resource conflicts (Daniels and Walker, 2012).

The Circle of Conflict (Fig. B4) is a tool which attempts to look at "the primary facets of conflict" (Moore, 1986). Many people and groups have made adjustments to the Circle of Conflict, and this study used the one created in a previous work in Laramie (Jarvis, 2014).

The Circle of Conflict has six categories of conflict: value, data, interest, identity, relationship, and structure. Values are stakeholder principles or beliefs. Data conflicts are based on scientific data and information. Interests are what stakeholders want, need, fear or hope. Identity conflicts are based on how stakeholders identify themselves and other groups in a conflict. Relationship conflicts are negative experiences stakeholders have had with one another.

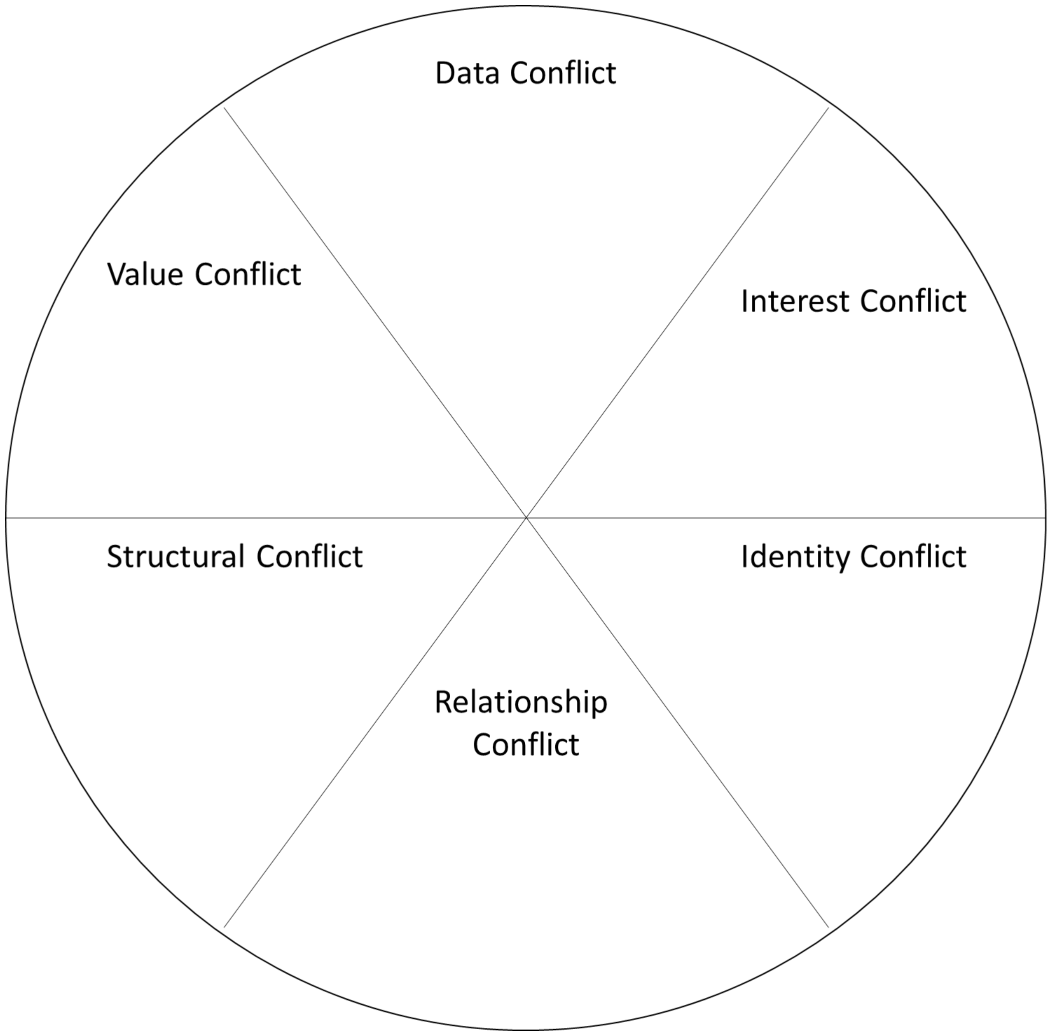

Fig. B4. The Circle of Conflict
Modified after (Moore, 1986)

Collaborative governance is when two or more groups pool power and resources between stakeholders for a common goal (O'Brien, 2012). Collaborative governance involves the creation of shared institutions and a shared culture between stakeholders. Collaborative institutions can take a variety of forms and have the flexibility to use both regulatory and non-regulatory approaches.

Collaborative governance institutions have existed for years (Ostrom, 1990). Since the 1990s, the number of collaborative institutions has grown (Pretty, 2003).

The newer collaborative arrangements are bottom-up collaborative decision-making groups formed by citizens, non-governmental organizations, and governments (Ansell and Gash, 2007; O'Brien, 2012). Collaborations have become more accepted and large central governments seek out collaborations and integration into government decision-making (Weber, 2013).

While there are many collaborative governance tools and frameworks (Daniels and Walker, 2001; Sabatier et al., 2005), there is no one standard tool (Weber, 2013). The collaborative governance tool for this study consists of a list collaborative governance concepts which focus on the conditions that promote collaborative arrangements or other policy approaches (Table B3).

When appropriate, the collaborative governance concepts were merged with situation mapping and the Circle of Conflict. This approach was taken because there was overlap between situation maps, the Circle of Conflict, and the collaborative governance tool.

Table B8. Collaborative Governance Concepts

Concept	Description	Reference
Committed Leadership	Leaders who are consistently involved over a long period of time.	(Pretty, 2003; Sabatier et al., 2005; O'Brien, 2012)
Communication	Open or closed channels of communication and forms of communication.	(O'Brien, 2012)
Existing problem	Problem which cannot be solved by traditional policy institutions and which causes conflicts.	(O'Brien, 2012)
Fatigue	Stakeholder tiredness or loss of interest in involvement in a conflict or institution.	(Rogers and Weber, 2010)
Institutional Flexibility/Stability	Longevity and adaptability of institutions (groups, regulations, etc.).	(Ostrom, 1990; Connelly et al., 2008)
History	Historical events or stakeholder lived experiences which help or hinder collaboration or conflict.	(Weber, 2013)
Outcomes	Substantive results or changes from putting an institution into place.	(Ansell and Gash, 2007; Emerson et al., 2012; Weber, 2013)
Power Disparities	Differences in power between stakeholders.	(Huxham, 2000; O'Brien, 2012)
Resources	General term for money, time, manpower, and other things needed for management.	(Ostrom, 1990; Sabatier et al., 2005; Sirianni, 2010; Emerson et al., 2012)
Shared Ownership, Responsibility, Vision, Culture and Knowledge	Values that are shared between all stakeholders. Collaborative Governance involves the creation of a shared institution and the creation of a shared culture between stakeholders who participate in the institutions.	(Ostrom, 1990; Daniels and Walker, 2001; Sirianni, 2010; O'Brien, 2012)
Social Capital	The potential for members of a community to work together to create institutions or activities.	(Ansell and Gash, 2007)
Stakeholder Interdependence	How stakeholders are related to each other and stakeholder's perspectives of those relationships.	(Ansell and Gash, 2007; Thomson et al., 2008)
Transaction Costs	The cost of communication or participating in an institution.	(Sabatier et al., 2005)
Trust	How much stakeholders trust other stakeholders.	(Sabatier et al., 2005; Thomson et al., 2008; O'Brien, 2012)

B4. Results

The stakeholder views discussed in this section represent generalizations based on the views expressed by stakeholders communicated with for this study. These views may not be representative of all members of the community, or of other individuals who are part of the stakeholder groups mentioned in this study.

B4.1 La Pine: Survey Results

The focus group and the initial survey activity had low attendance (one person for the focus group and six people at the initial survey activity). Three people who were only contacted through email showed initial interest in doing surveys but decided not to after seeing the survey materials and consent form. Three surveys were filled out; some of the surveys represent the views of multiple people, though the author was unable to tell due to the anonymity of the survey results.

Statistics are not presented due to the small sample size, and because statistics would not be representative of the La Pine community. Instead, a more qualitative narrative is presented based on the survey results. Some statistics were used to develop the qualitative narrative, such as averaging the results. All surveys were from people who were residents of the La Pine area.

From the surveys, all residents felt that they were knowledgeable about the NOWTS issue in La Pine. Though participants were knowledgeable, they had a wide range of views for the majority of questions on values and views of NOWTS in La Pine and this study. The other topic all participants agreed on was the need for regulations to be more flexible.

There was more participant consensus on other topics. For instance, participants were generally concerned with the Goal 11 regulations having standardized building codes, and they viewed OWTS which treated for nitrate as ineffective and too expensive.

Participants were neutral about the health effects of nitrate. They viewed the dangers of nitrate as being overexaggerated and specifically did not believe that nitrate caused blue baby syndrome (a symptom of methemoglobinemia). Blue baby syndrome was a highly political issue in La Pine because it was the main justification used by regulators, even though there were many causes of blue baby syndrome that did not involve methemoglobinemia. Participants felt that nitrate was not impacting the health of the community and would not in the future, although there was more uncertainty when predicting 100 years in the future.

Participants viewed a soil study the author was conducting concurrently with the surveys as credible but had neutral views about the understandability, satisfaction, fairness, and trustworthiness of the study. Participants had extreme views of the soil study methods, either finding all methods confusing or finding them all understandable. When asked how much they expected their views to be taken into consideration, participants tended to fall on the extremes of having their views ignored or having their views considered.

B4.2 La Pine: Situation Map

Two situation maps for the La Pine area were created based on the surveys, interactions with stakeholders in the La Pine Community, and public records. The first situation map represents the history of the conflict in La Pine from 2000 to 2019. The second situation map represents the conflict as things stand in 2019. These distinct situation maps were created to show how the conflict has changed over time.

From the situation maps, the main regulatory stakeholder groups are Deschutes County and ODEQ. Both of these groups operate and have membership outside of the La Pine Area.

Since 2000, NOWTS conflicts in the La Pine area have centered around efforts by Deschutes County to study and regulate the area as part of the South Deschutes County Groundwater Protection Project. This effort led to a series of studies and regulations in the La Pine Area. The regulatory efforts by ODEQ and Deschutes County brought in other groups, including:

- NGOs (Deschutes County Citizen's Action Group (CAG), Central Oregon LandWatch)
- Public Lands (controlled by US Forest Service, Bureau of Land Management, and Deschutes County)
- Private Lands (owned by residents, businesses, and ranchers)
- Funding (EPA and USDA)

As of 2019, Deschutes County and ODEQ remain the main regulators for NOWTS issues in the La Pine Area. Many of the groups who were active in NOWTS issues in the La Pine area have become less active in these issues in 2019. Developers continued to be a vocal group in NOWTS issues in 2019. The developers had issues with regulations that increase the cost of development (TDC) or with ODEQ requiring the use of OWTS that treated for nitrate (Shumway, 2019). NOWTS continues to motivate sewer construction in the City of La Pine, Water Wonderland, and Sunriver (Hamway, 2018).

Detailed explanations of the elements that compose the situation map are in the Literature Review.

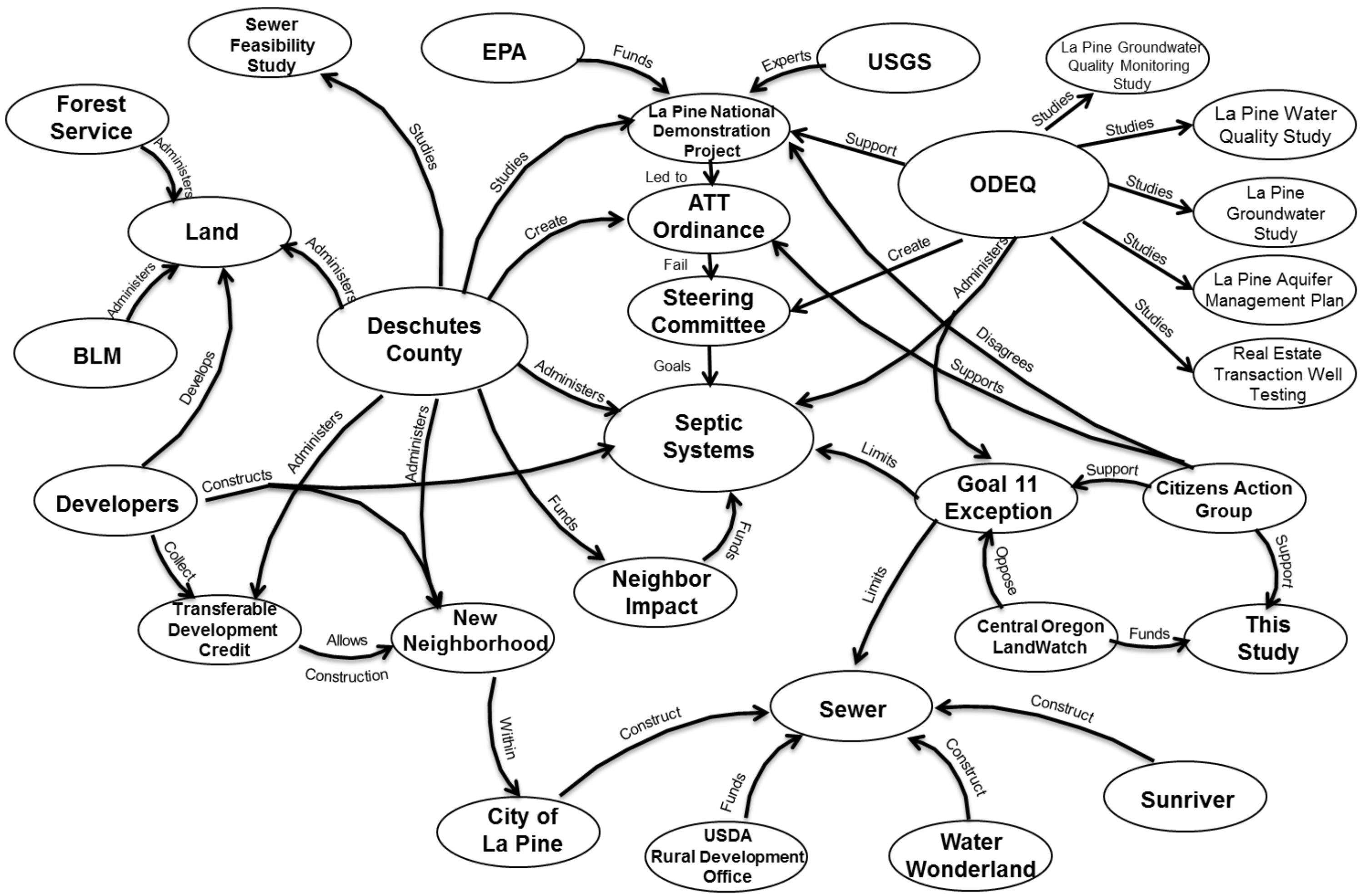

Fig. B5. Situation Map of NOWTS Conflict in La Pine, OR from 2000-2019
Explanation: ODEQ – Oregon Department of Environmental Quality, BLM – Bureau of Land Management, EPA – US Environmental Protection Agency, USGS – US Geological Survey

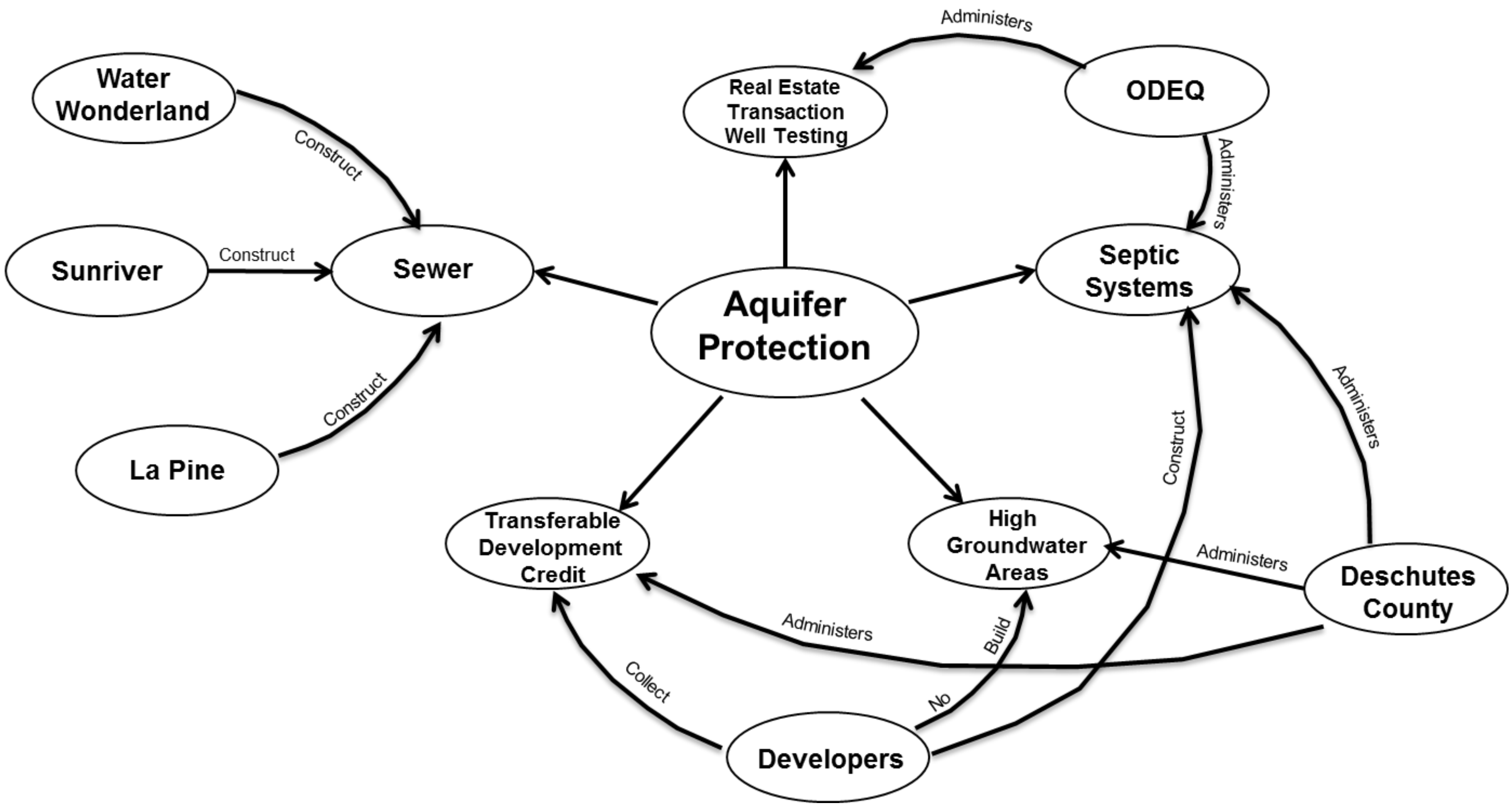

Fig. B6. Situation Map of NOWTS Conflict in La Pine 2019
Explanation: ODEQ – Oregon Department of Environmental Quality

B4.3 La Pine: Circle of Conflict

One factor in the conflicts in La Pine was the structure of the conflict. ODEQ and Deschutes County are government agencies, which are bound by state laws to take regulatory actions when nitrate levels in groundwater are above 10 mg/L in private and public wells. Deschutes County's actions included regulations on land use and septic systems based on studies (Nigg and Baggett, 2013). The regulations were applied regionally, so that investigations and judgements did not have to be made on a case-by-case basis.

The regulations were seen as a power disparity by residents, because regulations were put in place by county and state agencies using a "command and control" approach and residents felt that they had little say in the studies and regulations.

Residents of the La Pine Area had the expertise to oppose the regulations by contesting the studies used to formulate regulations. Stakeholder arguments focused on how information provided by scientists and the government conflicted with local knowledge. Stakeholders also found alternate political arenas in which to oppose the regulations, such as elections, Land Use Board of Appeals (LUBA), and litigation. For example, some residents felt that it was easier to affect elections in La Pine because the population of the area was ~18,000, and if 20% voted, only 1,801 people were needed for a majority.

There was poor communication between technical experts and stakeholders, which weakened technical expert credibility. Examples of poor communication were:

- The spread of nitrate contamination was shown through the worst case scenario model, which did not agree with residents' experience (Williams et al., 2007).
- Some stakeholders viewed NOWTS regulations as a direct attack on their livelihoods, or as a personal attack.
- The health effects of nitrate and the risk nitrate posed to the community were explained poorly to stakeholders. Stakeholders took divergent views on the health risks of nitrate based on how they viewed the broader of nitrate contamination issue.
- Some of the 2010 steering committee members viewed ODEQ and Deschutes County experts who presented to the steering committee members as "arrogant."

Some stakeholders opposed regulations because nitrate was viewed as less of a problem and because the regulations affected property rights, restricted development, and increased costs. In the La Pine Area, the cost of a conventional septic system was $2,000-12,000 for installation, plus $200-400 for maintenance every 3-5 years. Septic system retrofit to treat nitrate cost $2,250-18,000 with an additional $250-400 in yearly maintenance. Sewer was the most expensive, with $19,000-28,000 for sewer connection and $20-30 in monthly fees (DCCDD, 2007). Some stakeholders who opposed regulation were willing to compromise on regulations if they were more flexible, if they were enforced on a case-by-case basis, and if regulators took measures to lessen the impact of regulation on current residents.

Other stakeholders supported the regulations because they viewed nitrate as more of a problem and wanted to protect human health from nitrate contamination, keep groundwater uncontaminated, use NOWTS regulations to restrict development, and preserve the environment and rural aesthetics of the area.

Stakeholders were split based on the urban-rural divide in NOWTS conflicts in La Pine. The majority of policymakers or technical experts who had studied or were responsible for regulating NOWTS issues were from outside of the La Pine area. The main government offices for Deschutes County and the regional office for ODEQ are both located in the City of Bend, OR. There was sentiment among residents in La Pine that they were separate from the rest of Deschutes County, and in the media they were referred to as "south county" (Benson, 2008).

Residents of the La Pine area valued a rural lifestyle and supported actions which made living in rural areas sustainable, such as land stewardship, affordability, independence from central utilities, decreased government oversight, and privacy. The values surrounding rural lifestyles limited the forms of communication and increased the transaction costs of stakeholder communication. For example, canvasing and going door-to-door are not possible because stakeholders in the La Pine area consider it rude.

Despite a history of strained relationships in the La Pine Area, many of the stakeholders were willing to communicate. ODEQ and CAG have found areas of agreement, such as a need for more groundwater quality studies of the area and for stakeholder outreach and education. Though technical professionals had stories of being angrily yelled at while doing fieldwork in the La Pine area, this was not experienced by the author, and in professional settings people remained reserved even when frustrated.

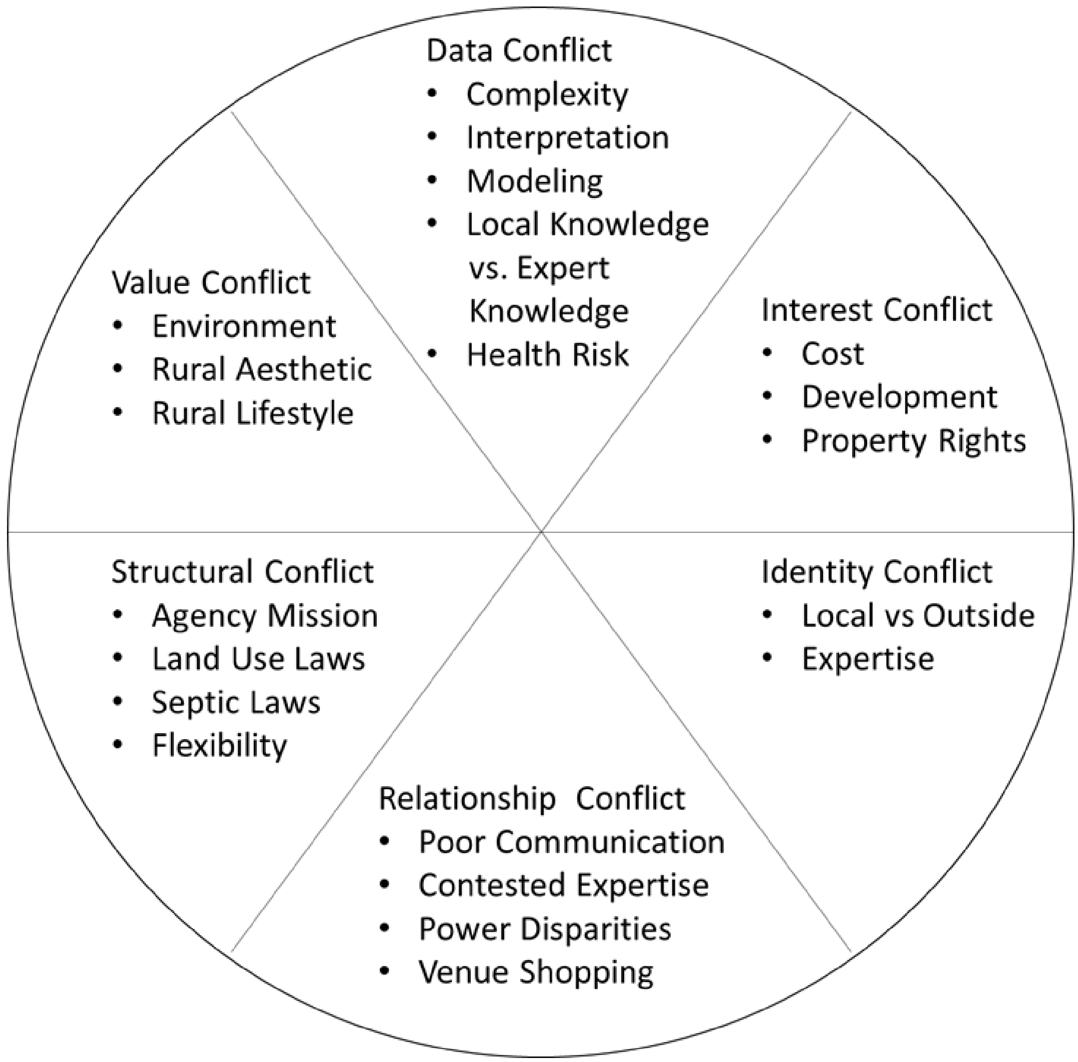

Fig. B7. La Pine Circle of Conflict

B4.4 Collaborative Governance

In collaborative governance, outcomes are not just results of the collaborative process. Outcomes provide incentive for stakeholders to participate in collaborative processes, and they represent substantiated accomplishments (Ansell and Gash, 2007; Weber, 2013).

Although there have been some substantive policy outcomes in La Pine, many of the larger changes were stopped by stakeholder opposition. The lack of substantive outcomes and a slowdown in actions by regulatory agencies has led to stakeholder fatigue and a lessening of interest in NOWTS issues in La Pine.

Fatigue can deter stakeholders from participating in the collaborative process (Rogers and Weber, 2010). Deschutes County, ODEQ, and CAG have expressed fatigue and have all been less active on NOWTS issues. This fatigue took multiple forms:

- Many members of CAG were older, and during the time of this study some members passed away or had major health issues.
- ODEQ and Deschutes County lacked resources to fund activities.
- Some residents were frustrated because they felt that OWTS regulations were constantly shifting, creating uncertainty over how to follow the law and develop their property.

Groups have had varying levels of commitment to addressing NOWTS. Technical experts who worked for ODEQ and Deschutes County, as well as NGO members, have been consistent participants in the NOWTS conflict. Government leadership has not been consistent; the Deschutes County Commissioners and the head of ODEQ have changed multiple times during this conflict. NGOs have had varying levels of involvement in NOWTS conflict, depending on how much their membership was impacted by NOWTS issues.

Groups that have been involved in the NOWTS issues in La Pine for a long time communicate well, share information, and know the position of the opposing groups. Since there is no common view of NOWTS among groups, it is difficult to make policy on NOWTS issues, because the regulations may impinge on any one group.

Information on all stakeholder groups, active regulations, and conflicts in La Pine was available online. The plethora of available information increased the difficulty of familiarizing new stakeholders with the issues, and there was higher risk of new stakeholders being confused by the information (Sirianni, 2010).

B4.5 Laramie: Interview Results

Results for Question 6, which asked whether stakeholders had anything else to share, were added to the results for the question to which they were most applicable.

B4.3.1 What is your connection to the Casper Aquifer?

Stakeholders were categorized based only upon how they self-identified in interviews. The connection shared by all of the stakeholders interviewed was that they derived some if not all of their water from the Casper Aquifer. Most stakeholders identified themselves first by their connection to the aquifer either, as well owners or as being on municipal water supplies, ~60% of which comes from the aquifer.

Table B9. Primary Interests

Interest	#	Definition
Laramie City Councilor	2	A member of the legislative body that governs the City of Laramie.
Albany County Commissioner	2	A member of the group that administers the Albany County government.
Private Well Owner	3	A person whose dwelling is outside Laramie City Limits and within the Casper Aquifer Protection Area, and whose water source was a private domestic well that draws water from the Casper Aquifer.
Well-Owner Professional	2	An engineer or scientist who was employed at a groundwater- or water-related consulting firm in the Laramie area. Members self-identified as hydrogeologists or geologists. *Well-owner professional* was used because they primarily identified as well owners.
EAC	1	A member of the Environmental Advisory Committee, which is composed of members from the City of Laramie and Albany County.
Albany County Planning Department	1	An employee for the Albany County Department in charge of land use planning, permitting, and enforcement.
No-Well Professional	2	An engineer or scientist who was employed at a groundwater- or water-related consulting firm in the Laramie area. Members self-identified as hydrogeologists or geologists. The term *no-well professional* was used to differentiate stakeholders who primarily identified as water professionals but were on public water supplies.
Law Firm	1	Legal representative for nonresidential land owners in the CAPA.

B4.3.2 Do you know the past 40 year history of issues surrounding the Casper Aquifer?

The events identified by all of the stakeholders interviewed were that there was little conflict over the creation of the Casper Aquifer Protection Plan in 2002, that conflict escalated after the plan came into effect, and that in the past few years there had been a de-escalation in the conflict.

The individual histories were personal, and stakeholders often focused on their own or their group's role in historical events and on events which were important to their group. Some of the stakeholders' (EAC) histories were more general than other groups (no-well professional, well-owner professionals, and private well owners) whose histories had many specific events.

Stakeholder histories covered a range of time periods. Private well owners started at the founding of the City of Laramie, while the Albany County Planning Department member started with their involvement in the conflict as part of County Planning.

B4.3.3 What issues relating to the Casper Aquifer are most important to you?

All stakeholders were concerned with keeping the water "clean" for posterity. The term "clean" was defined differently by stakeholders, from water having no contaminants to water meeting quality standards for public water systems to the aesthetics of water.

Other views and perspectives shared by the majority of stakeholders were:

- Concerns over the potential for accidents and spills on Interstate 80.
- Support for the Pilot Peak Project.
- Support for more CAPA studies.
- Support for more stakeholder education.
- Fatigue experienced in some form by stakeholders
- Optimistic view of water quality in the Casper Aquifer.

More divisive concerns were the effects of regulations on property rights, land values, and costs of regulation for private well owners and businesses (private well owners, County Commissioners, and Law Firm).

Stakeholders on all sides of the conflict accused the opposition groups of producing biased science or of manipulating information.

Private well owners, well-owner professionals, and county commissioners interpreted the available data as establishing that septic systems contribute little to nitrate contamination of the Casper Aquifer, or that there was not enough evidence to prove that septic systems were contaminating the aquifer. These groups viewed nitrate in groundwater as coming from other sources, including nitrogen fixation by plants, unsealed or improperly constructed wells, and historic sheep ranching. Private well owners, well-owner professionals, and county commissioners wanted to protect landowner privacy by keeping nitrate data private, because there were concerns that the data would be used against private well owners.

The interpretation of no-well professionals was that existing private wells had elevated nitrate concentrations over public drinking water standards, and consequently, regulatory action should be taken. These groups wanted data to be publicly available so that there could be more review and oversight of data.

B4.3.4 What other groups or individuals are involved in issues surrounding the Casper Aquifer?

All the stakeholders interviewed had a wide perspective of the groups involved in the Casper Aquifer, though the number of other groups mentioned varied by group, and specific groups mentioned were the ones the stakeholders interviewed were most familiar with. In the words of an interviewed no-well professional, "We are all stakeholders of the Casper Aquifer."

The CAPA stakeholders were aligned based on the urban-rural divide, with members of rural groups (private well owners, well-owner professionals, county commissioners, and CAP Network) having negative views of urban groups (City

Council, no-well professional, ACCWA) and vice versa. The negative views of urban and rural groups persisted, due to the history of conflict and miscommunications between the groups.

The rural groups viewed the urban groups as being too emotionally invested in CAPA issues, as being too quick to use strict regulatory measures, and as not following the “rules.” The “rules” referred to legal rules, procedural rules, laws, regulations, agreements, societal norms, litigation, or perceived manipulation of the “rules.”

Both urban and rural groups accused the other of creating biased science or of having a conflict of interest. Biased science was a greater part of the negative views urban groups had of rural groups in interviews. In the view of the stakeholders interviewed from urban groups: rural groups’ support of property rights was a conflict of interest with aquifer protection, rural groups used rhetoric to lessen the impact of technical expert findings, and rural groups were not transparent with their use of scientific data. On the other hand, rural groups felt that urban groups used science to target rural groups or designed studies in a way that pushed an agenda.

The Law Firm, Albany County Planning Department, and EAC were seen by other groups, and viewed the other groups, more neutrally.

Many other groups were mentioned that played a smaller role in the conflict. Approval from WDEQ and the Groundwater Foundation lent legitimacy to stakeholder groups and the CAPP. There were many state agencies whose jurisdiction intersected with CAPA issues, such as the Wyoming Department of

Transportation (WYDOT), State Engineer, State Parks, and Wyoming Water Development Commission. UW students and faculty, Oregon State University, the US Geological Survey, and some consulting firms were considered to be objective in their work on the CAPA.

B4.3.5 What is your desired outcome for the Casper Aquifer Protection process?

All stakeholders wanted to have a "clean" aquifer but disagreed on the "problems," such as the cause of aquifer contamination, the concentration of nitrate when action would be taken, and the risks posed by nitrate contamination. Stakeholders proposed different "solutions" based on their view of the "problem."

All stakeholders wanted more aquifer studies and for science to be involved in creation of regulation, but stakeholders disagreed on how this was achieved. No-well professionals wanted information to be more publicly available over the internet and for the CAPA to be updated based on information gained since the creation of the CAPA. The Law Firm wanted CAPA regulations to allow more activities if engineered mitigation measures were used. County Commissioners wanted to avoid regulating until there was an aquifer contamination "problem."

City Council and no-well professionals wanted to limited development on the CAPA. Rural groups wanted to not be bothered by regulators (private well owners, well-owner professionals, and county commissioners) and to balance CAPA regulations with property rights (private well owners, county commissioners, and County Planning).

The interviewed private well owners and county commissioners perceived multiple positive outcomes from participating in the CAPA conflicts, such as enhanced communication between private well owners. Private well owners also gained knowledge of septic systems, wells, and the Casper Aquifer by participating in the conflicts.

Outcomes that crossed the urban-rural divide included the desire for everyone to work together (EAC, no-well professional, County Planning Department, City Council) and interest in the use of OWTS that treated for nitrate (county commissioner, EAC, no-well professional)

The outcomes wanted by the majority of stakeholders were for more spill prevention measures on Interstate 80, purchasing the Pilot Peak Project, and more stakeholder outreach and education.

Table B10. Laramie Interview Results

Primary Interest	Secondary Interests	Connection to Aquifer in the words of stakeholder	Issues	Other Groups	Outcomes
Laramie City Council (2)	*Former* County Commissioner (1) *Former* Planning Commission (1)	Source of 60% of Laramie's water. To protect and keep the aquifer clean.	Clean Aquifer (2) Costs (1) City less than 4% CAPA (1) NO_3 Contamination (2) I80 Spills (1) Only 2 monitoring wells (1) Trust (1)	ACCWA (1) County Commissioners (2) CAPA Resident (1) Concerned Citizens (2) Water Professionals (1)	Clean Casper Aquifer (1) Limit development (1) Protect city water (2) Pilot Peak Project (1) Continuing process (1)
CAPA Resident (3)	CAP Network (1) Inactive CAP Network (1)	Homeowners whose only source of water is the Casper Aquifer.	Clean Aquifer (3) Connection to City utilities (1) Development (2) Education (1) ATT (1) I80 Spills (2) Costs (1) Livestock (1) Old Wells/Septic (2) Property Rights (1) Regulation (2) Trust (1) Water Quantity (1) More Data (1) Biased Science (1)	ACCWA (2) County Commissioners(2) CAP Network (2) CAPA Residents (2) Water professionals (1) Groundwater Foundation (1) City Council (2) Property Owners (2) Septic Pumper (1) State Engineers (1) WDEQ (1)	Be left alone if follow rules. (3) Decrease speed limits on I80 (1) Education (1) County to protect CAPA Residents. (1) Inventory septic (1) More data (2) Science-based regulation (2) Study existing wells (1) Connect to neighbors (1)

Continued on next page

Table 12. Laramie Interview Results *Continued*

Primary Interest	Secondary Interests	Connection to Aquifer in the words of stakeholder	Issues	Other Groups	Outcomes
CAPA Professional (2)	CAPA Resident (2) Water Professional (2) CAP Network (1)	Homeowners whose only source of water is the Casper Aquifer.	Clean Aquifer (2) Interstate 80 Spills (1) Old Wells/Septic (1) Costs (1) Regulation (1) More Data (1) Education (1) Property Rights (1) Donut (1) Biased Science (1)	WY DOT (1) City Council (1) CAP Network (2) CAPA Residents (2) Primary Professional (1) USGS (1) UW (1) County Commissioner (1) UW (1) OSU (1) ACCWA (1)	Decrease speed limits on I80 (1) Be left alone if follow rules. (2) Continued access to water (1) Stakeholders not jumping to conclusions (1) More sampling (1) Science-based regulation (2)
Environmental Advisory Committee (EAC) (1)		Advises the City and County on environmental issues.	Clean Aquifer Aquifer resource Laramie is in a good position Education Public Heath Septic systems are a touchy subject	ACCWA Property Owners	Continue working in the right direction No NO_3 from fertilizer Education

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Table 12. Laramie Interview Results *Continued*

Primary Interest	Secondary Interests	Connection to Aquifer in the words of stakeholder	Issues	Other Groups	Outcomes
Primary Professional (2)	Contractors (1) Professional Academics (1) Consultant (1) Laramie Resident (1) Technical Committee (1)	Professionals who study the aquifer and provide best information on the aquifer.	Clean Aquifer (2) Community of Users (1) Control of Information (2) Good Science (2) Honest assessment of septic areas (2) I80 spills Little dialog between groups (1) Pilot Peak (1) Trust (1) Update CAPA with new information (1) Elevated nitrate in subdivision wells (1) Urban vs. rural (1)	ACCWA (2) County Commissioners(2) CAP Network (2) City Council (2) Water professionals (2) CAPA Residents (2) WDEQ (1) EAC (1) Everybody (2) Laramie March for Science (1) Pilot Hill Committee (1) Seniors (1) UW (1)	City and County work together (1) I80 Spills study and plan (1) Impermeable rock between septic and aquifer. (1) Less/less dense development on CAPA (2) Objective science (2) People will be technical (2)
Albany County Commissioner (2)	• CAPA Resident (2) • Septic Company (1)	Residents and policymakers of Albany County who obtain water from the Casper Aquifer.	Clean Aquifer (2) Accurate data (1) ATT (1) Avoid Litigation (1) Education (2) I80 Spills (1) Pilot Peak Project (1) Property Values (1) Recreation (1) Trust (1)	ACCWA (1) CAP Network (1) CAPA Residents (1) City Council (2) County Commissioners (2) Concerned Citizens (2) Water Professionals (1) Septic Pumper (1)	Balance regulation with available data (1) City and county work together. (1) Keep Casper Aquifer clean. (1) Science informing Policy (2) Unbiased Science (1)

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Table 12. Laramie Interview Results *Continued*

Primary Interest	Secondary Interests	Connection to Aquifer in the words of stakeholder	Issues	Other Groups	Outcomes
Albany County Planning Department (1)		Ensures the goals of the CAPP are implemented and that development follows adopted regulation.	Balanced viewpoints Good Information Protect the Water Supply Trust	ACCWA Albany County CAP Network Concerned Citizens Laramie State Engineers WDEQ WYDOT	Balance aquifer protection and benefits of landownership.
Law Firm (1)	Nonresidential Landowners	Represents most of the large landowners on the CAPA.	Protect water and clients' land use rights Represent Nonresidential Landowners Science-driven regulation	ACCWA CAP Network Landowners Local Government Nonresidential Landowners State Engineers State Parks State of Wyoming WDEQ Wyoming Water Development Commission	CAPP updated every 5 years. Updates to allow for mitigation or safety measures for potentially contaminating land uses.

Explanation: The number in parenthesis represents the number of participants who touched upon the topic or identity. Albany County and Laramie are general terms for all groups that are part of the Albany County government and government of the City of Laramie. These terms are used because they were used by the stakeholders interviewed.

B4.6 Laramie: Conflict Management Tools

This study builds upon, rather than duplicates, the historic work by revisiting the Casper Aquifer situation in 2018 (Jarvis, 2014). The situation maps and Circles of Conflict show the evolution of the CAPA conflict over time (Table B10).

From the situation maps, CAPA conflicts started in the 1990s and grew in intensity and sophistication, drawing in more groups as CAPA regulations were put in place. Since 2013, the conflict has de-escalated and many groups (UW and state agencies) have been less active in the conflict. Within the greater trends of escalation and de-escalation, there have been smaller conflicts when the city, citizens, or urban groups push to stop or slow development on the CAPA.

Based on the 2013 and 2018 situation maps and the Circles of Conflict, the divide between the City of Laramie and Albany County has been a consistent part of the CAPA conflict. The divide was related to CAPA conflicts though jurisdiction, regulations, urban-rural divide, and shared government institutions. Until HB 85 and HB 14, there was a perceived power disparity between private well owners and the City of Laramie because the city could place regulations on private well owners, but private well owners could not vote or hold positions in city government.

The City of Laramie and Albany County took divergent approaches to aquifer studies. Studies supported by the City of Laramie focused on nitrogen contamination of groundwater and public water supplies (City of Laramie, 2010; Schroeder et al., 2013; Hinckley and Moody, 2015), while studies supported by Albany County focused on septic system operation, release of effluent to the vadose zone (Wenck Associates, 2019), and potential contamination from Interstate 80 (Athey, 2011).

Part of the reason for the divergent approaches to studies was because stakeholders at all levels of expertise were more knowledgeable about the Casper Aquifer and NOWTS, so they could develop their own questions about contamination of the Casper Aquifer. There were also resources available for citizen's groups and students to conduct their own science projects or to push the government to conduct studies to address their concerns. The use of science created by residents is contentious in Laramie and is covered in greater detail in Appendix D.

The relationships between all stakeholders changed during the conflict period. Relationships were relatively calm, but as the conflict escalated in 2013, all stakeholders were more adversarial and had immediate emotional responses to CAPA conflicts.

The stakeholders interviewed (CAPA residents and no-well professionals) noted that landowners felt a mix of strong emotions when they learned that their well was contaminated or that they had a failing septic system, since they did not want to contaminate groundwater, drink contaminated water, or be accused of contaminating the aquifer. Both groups (CAPA residents and no-well professionals) wanted to assuage land owners, since these situations are uncontrollable but steps could be taken to remedy these situations.

In interviews, stakeholders noted that as the conflict de-escalated, immediate emotional responses decreased. Instead of immediate emotional responses, conflicts were perpetuated by feedback loops of mistrust between stakeholders. Stakeholders had negative past experiences with each other, and thus stakeholders had negative opinions of other groups. The negative opinions led to misinterpretation of other stakeholders, thereby creating more negative experiences.

The overall views of the groups who remained active in CAPA conflicts were relatively unchanged between 2013 and 2018, though there were differences for very specific topics that were relevant at the time.

The stakeholder views highlighted the divide between urban and rural stakeholders. The City of Laramie was a community where property rights and the collective "greater good" were valued.

Though there were ideological divides between groups who were identified as "city" residents and "county" residents, there was a high degree of interaction between groups:

- The majority of private well owners live in subdivisions within a mile of Laramie city limits.
- Stakeholders share views and societal norms.
- Private well owners work, shop, go to school, and use services in Laramie.
- The offices of the City of Laramie and Albany County governments are within walking distance of each other.

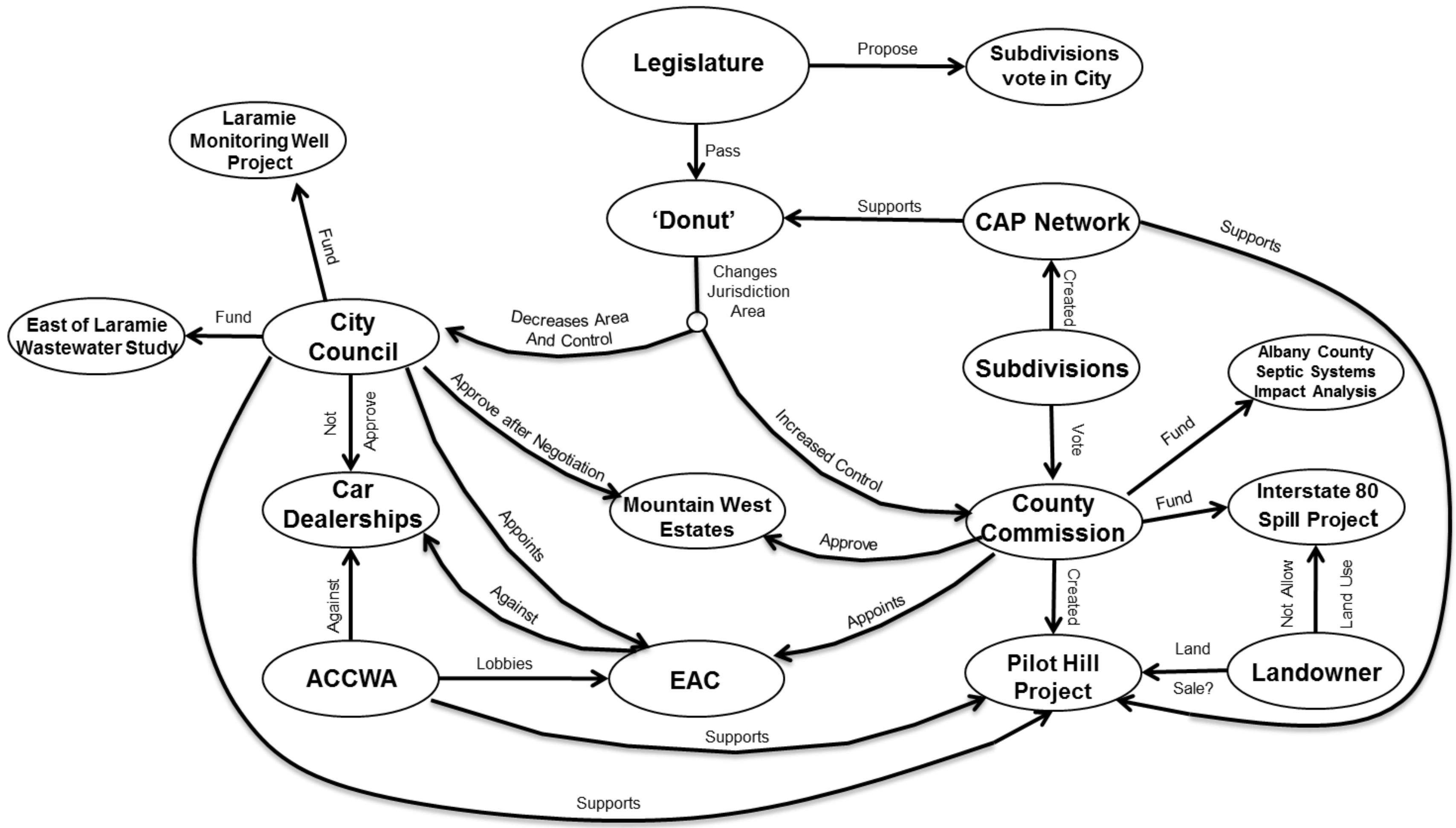

Fig. B8. CAPA Situation Map 2013-2018

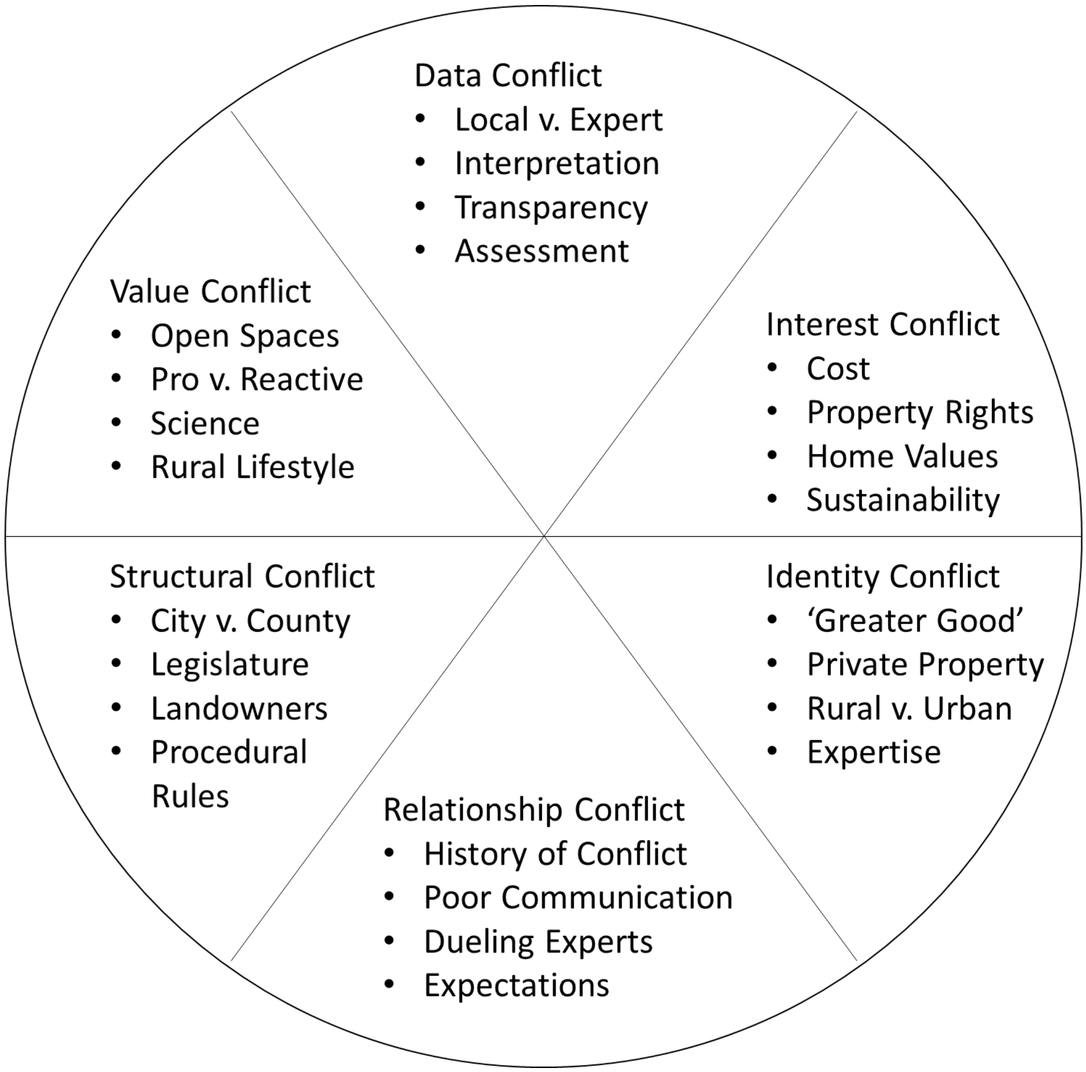

Fig. B9. CAPA Circle of Conflict 2013-2019

Table B11. Changes in Situation Maps and Circles of Conflict 1990-2018

Topic	1990	2013	2018
Situation Maps	Fewer elements as plans were developed.	Many elements during the height of conflict. Opposing sides, city and county.	Decrease in elements as conflict de-escalates. Many groups are less active in the conflict.
Values	Science Risk Precautionary Principle	Open Space Drinking Water Science Rural Lifestyle	Open Space Proactive vs. Reactive Science Rural Lifestyle
Data	• Interpretation • Assessment	• Interpretation • Assessment • Lack of Data • Missing Data • Procedures	• Interpretation • Assessment • Local v. Expert • Transparency
Interest	• Business Opposition. • Competition • Procedure	• Property Rights • Home Values • Future Gens.	• Property Rights • Home Values • Sustainability • Cost
Structural	• City v. County • Rural v. Urban • Landowners	• City v. County • Legislature • Landowners • University	• City v. County • Legislature • Landowners • Procedural Rules
Relationship	• Dueling Experts	• Dueling Experts • Poor Communication • Emotions	• Poor Communication • Dueling Experts • History of Conflict • Expectations
Identity	• Reputation • Recognition	• 'Greater Good' • Private Property • Urban vs. Rural	• 'Greater Good' • Private Property • Rural v. Urban • Expertise

Explanation: The situation maps and circles of conflict were condensed in this table. The 2018 column under the situation map row is a description of Fig. B8. The 2018 column under the Circles of Conflict row is the same information as in Fig. B9 but in table from instead of a wheel diagram. The Circles of Conflict are displayed in table form instead of in wheel diagrams and all the information is retained. The full situation maps and Circles of Conflict for 1990 and 2013 are from Jarvis (2014).

B4.7 Collaborative Governance

A variety of collaborative governance issues were touched upon in stakeholder interviews.

Many of the interviewed stakeholders wanted to build trust between groups and wanted the City of Laramie and Albany County to work together. Stakeholders had worked together in past activities (2002 CAPP, Pilot Peak Project, and past regulations). All of the stakeholders interviewed spoke about how active stakeholders were in local politics surrounding CAPA. Stakeholders also noted how one or a small number of dedicated individuals could successfully push for government action.

All of the stakeholders interviewed wanted to build trust between stakeholders by creating a shared pool of knowledge containing “good” information as a way to resolve data conflicts. The barriers to creating a shared pool of knowledge were disagreements over what was “good” information and differences in the perceived expertise and legitimacy of stakeholder groups.

There were both limitations and advantages to the information being collected by stakeholder groups. Technical experts faced resource and political limitations when conducting studies. Science conducted by residents was able to overcome some of the political limitations, such as using practices that were not viewed by opposing technical experts as credible.

Many of the stakeholders interviewed had been involved in CAPA conflict since the 1990s and showed signs of fatigue:

- There was frustration over difficulties involved in the CAPA process and with other stakeholders.

- Groups wanted to find successors or educate the next generation to work on CAPA conflict.
- Some groups were satisfied with the current state of CAPA policy.
- The conflict became less active and less contentious.

B5. Discussion

This discussion builds upon the information provided in the results section, comparing how stakeholders in La Pine and Laramie viewed the conflicts and identifying aspects of the setting and history of conflict that may have motivated stakeholder views. The information in this section is based on views stakeholders in La Pine and Laramie expressed in surveys, interviews, and other communications.

B5.1 Comparison of the Conflict Settings in La Pine and Laramie

While the both La Pine and Laramie have conflicts over NOWTS, the conflicts are subtly different. On the individual home scale the NOWTS issues in La Pine and Laramie are similar, but on the regional scale they are very different. In La Pine, there was disagreement over the potential of NOWTS to contaminate water in subdivisions and streams. In Laramie, there was disagreement over the potential of NOWTS to contaminate the public water supply for the City of Laramie.

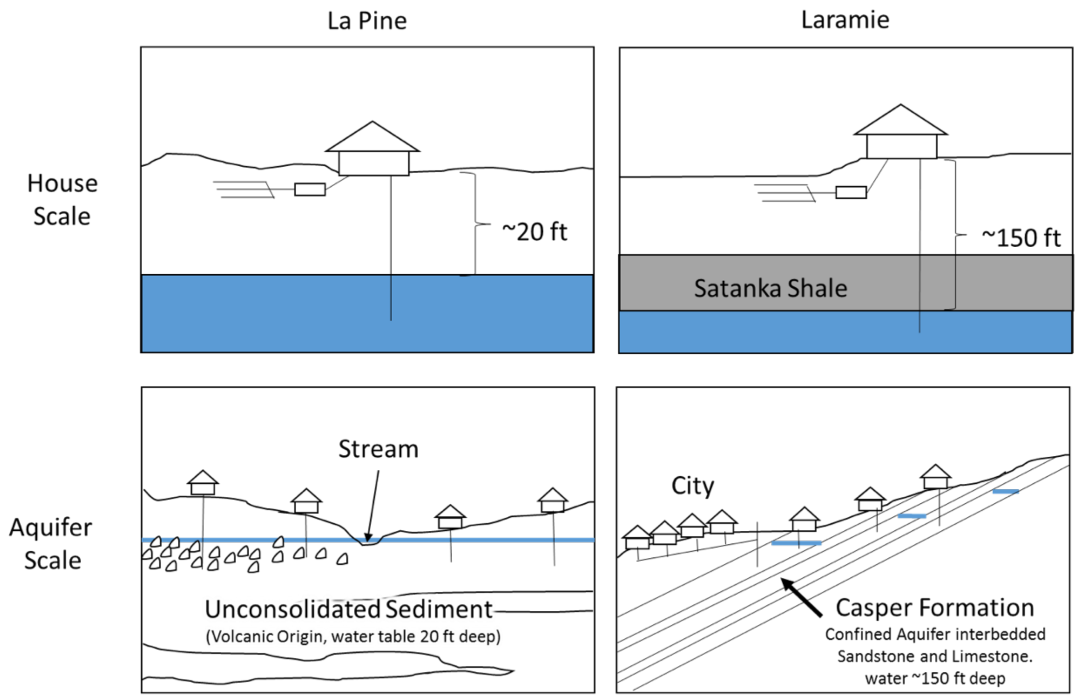

Fig. B10. Hydrology of La Pine and Laramie

The hydrology and demographics could have shaped regulations and stakeholder arguments. In interviews in Laramie, stakeholders mentioned the hydrogeology and technical aspects of septic systems more than stakeholders in La Pine did. In La Pine, stakeholders mentioned the health risks more than stakeholders in Laramie did. The focus in Laramie could be due to the consolidated sediment stratigraphy, which is well defined (Fig. B10). In La Pine, because sediments are unconsolidated and complexly layered, it was more difficult to argue about specific aspects of the geology, since the geology was uncertain.

The demographics of La Pine and Laramie created different structures for the urban-rural divide. In Laramie, stakeholders on either side of the urban-rural divide used the same water source, and the majority of rural residents lived within 1 mile of

Laramie. In interviews, stakeholders in Laramie spoke about how the conflict affected friendships.

In La Pine, there was a greater separation along the urban-rural divide since urban groups were in Bend, 28 miles away. As a result, NOWTS conflicts had little effect on existing personal relationships.

Despite the differences in the structure of the urban-rural divide in La Pine and Laramie, there were many similarities in terms of power disparities, values, and interest. In conflicts in both La Pine and Laramie, there was a power disparity in that urban governments had the ability to regulate rural areas, which was met by resistance from rural residents who were not/less represented in urban governments. The power disparities shifted over time, giving rural residents more influence in decision-making.

The values expressed by urban and rural residents were similar in La Pine and Laramie. Urban and rural residents both wanted to protect groundwater using science but differed on how this was accomplished. Urban groups wanted stronger land use regulations to stop any potential groundwater contamination. Rural groups wanted regulations to take into account the impact regulations had on personal costs and property rights.

The values attached to rural lifestyle/aesthetics were similar in La Pine and Laramie: favoring privacy, property rights, independence, and less government oversight, as well as being less risk averse. On the other hand, urban groups valued the "greater good" and were more risk averse.

B5.2 Historical Comparison of Conflicts in La Pine and Laramie

The history of the conflict affected stakeholders in three ways: (1) stakeholder knowledge, (2) view of other stakeholders, and (3) fatigue.

As stakeholders (including residents, regulators, and experts) participated in conflicts, they became more knowledgeable about the science and politics behind the conflicts. For example, in La Pine, stakeholders found more strategies for addressing NOWTS issues, and they were willing to compromise on some regulations.

Stakeholders also learned about NOWTS through many different sources (documents, conversations, websites, personal experience, newsletters, etc.), which gave stakeholders different understandings of NOWTS. Stakeholders had different interpretations because the scientific theory behind NOWTS is well understood but NOWTS can vary greatly depending on local conditions (McLaren, 1976; Ahola, 2017). The different understandings of NOWTS made it so there was less agreement on issues involved in the conflict.

The differences in stakeholder knowledge made it so that there was no pool of commonly agreed-upon knowledge and there were many different views of the NOWTS "problem." The differing views created a situation in which technical experts were mistrusted, because stakeholders had to choose whether to trust technical experts they did not know over their friends and neighbors (who may also be technical experts). Stakeholder knowledge also created barriers to entry for new stakeholders, since they did not have the same experience or knowledge as stakeholders who were veterans of the NOWTS conflicts.

As stakeholders (including residents, regulators, and experts) participated in conflicts, they also formed opinions of other stakeholders based on their past interactions. These opinions colored future interactions stakeholders had with each other in ways that often reinforced their opinions. For example, when stakeholders had a negative opinion of another stakeholder, they would have less trust in the stakeholder and would be more likely to negatively interpret the stakeholder, which created conflicts that further reinforced the negative opinion. The inverse occurred for positive opinions.

The majority of stakeholders in La Pine and Laramie felt some type of fatigue with the conflicts. The amount of fatigue stakeholders experienced varied by individual; some groups showed signs of fatigue in less than a year, while for other groups it took decades. There were many symptoms of fatigue that included:

- A general sense of frustration over the conflict and groups involved.
- A lack of time, motivation, or resources to continue the conflict.
- Being more selective in choosing opportunities to address conflict.
- Wanting to find successors to continue the conflict.
- Some stakeholders were satisfied enough with the situation to not participate in the conflict.

Based on the NOWTS conflicts in La Pine and Laramie, there were two frameworks for thinking about stakeholder fatigue as either a feedback loop or an interest curve. The fatigue feedback loop (Fig. B11) is based on policy frameworks where policy actions create impacts that motivate further policy action (Ansell and Gash, 2007; Emerson et al., 2012). Fatigue is based on a cycle where either no actions are taken or there are no substantive outcomes, so stakeholders lose interest, decreasing the potential for future actions. One strategy for building stakeholder interest based on this framework is to use “small wins” (small projects or regulatory changes) to create substantive outcomes to build interest and stakeholder trust (O’Brien, 2012).

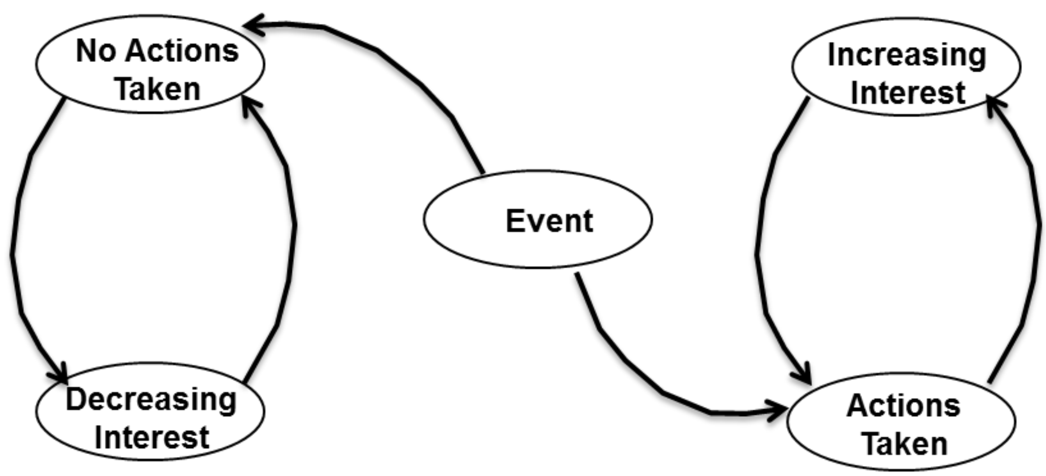

Fig. B11. Fatigue Feedback Loops

In La Pine, NOWTS conflict followed the trend in the fatigue feedback loop. Early in the conflict, ODEQ and Deschutes County created controversial regulations. Many of the more controversial regulations were blocked by residents and groups like CAG or Central Oregon LandWatch. Since ODEQ and Deschutes County had limited resources and there were few lasting regulatory changes, ODEQ and Deschutes County stepped back from the conflict. After governments stepped back from the conflict, other groups also stepped back.

The interest curve (Fig. B12) is based on interest curves from storytelling and game design, mixed with the view that events or crises motivate policy action (Table B2). In this view, stakeholders have a baseline interest in NOWTS, but interest peaks during controversial events or crises, followed by a slow loss of interest.

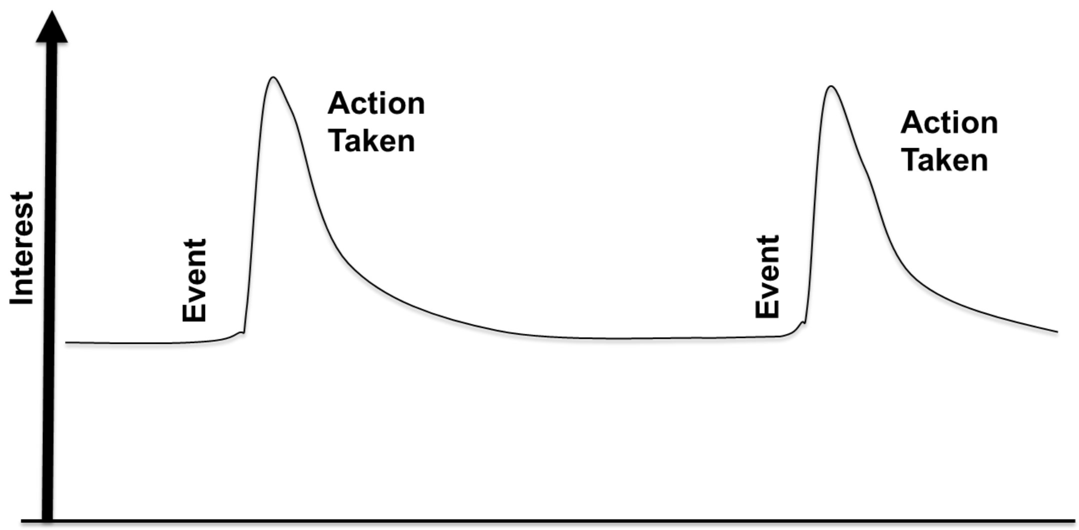

Fig. B12. Fatigue Interest Curve

One strategy to retain stakeholder interest based on this framework would be for groups to broaden the scope to issues outside of NOWTS and to build coalitions with other groups. By broadening the scope and building coalitions, more people are drawn in to the conflict and there are more events to act on, which keeps interest elevated (Karkkainen; Ostrom, 1990; Heikkila and Gerlak, 2005; Wolf et al., 2010). Broadening the scope is like overlaying multiple interest curves.

In Laramie, the trend in NOWTS conflict followed the fatigue interest curve (Fig. B12) because NOWTS was part of the broader issue of aquifer protection. Aquifer protection efforts continue to be active in Laramie due to the many sources of potential contamination (Achs, 2019c, 2019d, 2019b), conflicts with developers (Bendtsen, 2019a), and a complex regulatory landscape (Bendtsen, 2019b).

Addressing fatigue is a moral dilemma. On the negative side, fatigue decreases civic engagement and "solutions" have less consensus. On the positive side, fatigue creates “solutions” which are “good enough” to accept, “resolving” the conflict.

Though groups are fatigued in La Pine and Laramie, these communities continue to address NOWTS issues. The City of La Pine has expanded sewer services (Hamway, 2018), and developers continue to oppose the Transferable Development Credit Program (Shumway, 2019). Since the interviews in Laramie about the NOWTS conflicts, the city and county have cooperated on some projects, such as a new study on the potential for groundwater contamination from spills on Interstate 80 (Achs and Bendtsen, 2019) and on the Pilot Peak Project. While some NOWTS-based activities have been less controversial, conflicts in Laramie continue to periodically flare up (Achs, 2019a; Miller, 2019).

The role of experts and stakeholders in NOWTS science in La Pine and Laramie was highly complex and is explained more in (Appendices C and D)

B5.3 Methods

B5.3.1 Surveys in La Pine

The focus group and the initial survey activity had low attendance (one person at the focus group, six people at the initial survey activity). There were also three people, who were only contacted through email, who showed initial interest in doing surveys but decided not to after seeing the survey materials and consent form. Two people were spoken to outside for the framework of this study but decided not to participate.

The surveys could have been improved by having more explanation, since some participants were unfamiliar with survey format, and by removing “not applicable” or “no relation,” options since it was only use twice across all surveys.

Some stakeholders chose not to participate in the study because:

- Stakeholders did not want to sign consent forms or other privacy concerns.
- Stakeholders felt they would be strategic in answering questions, biasing survey results.
- Stakeholders who were familiar with survey methods or had high educational attainments felt they might unintentionally use their knowledge to manipulate results.
- Stakeholders were concerned that survey results could be used to trace their identity.
- Stakeholders were concerned that their involvement could make the study less credible since their views on NOWTS were well known.

B5.3.2 Stakeholder Interactions in La Pine

Though the main focus of this study was on stakeholder participation and views, there were many lessons learned as part of conducting this study. Organizing the study was complex because of the many parts: soil study (Appendix A), survey of stakeholders in La Pine, equipment, and stakeholders’ schedules.

There were many missed opportunities to improve stakeholder interaction and the quality of the study. At the time of the study, the decisions were sound, but in hindsight they could have been improved.

Table B12. Discussion of Stakeholder Interactions in La Pine

Topic	Prediction/Rationale	Observation	Improvements
Recruitment	• Start recruitment one month to two weeks before start of study (Robson, 1993). • Mailed, posted fliers and spoke to stakeholders.	Small number of participants.	• Have longer term recruitment. Longer term recruitment could be at public events: rodeo, Frontier Days, July 4th, local government meetings. • This would help to increase researcher and stakeholder familiarity and build trust.
Time of Year	August was when there were few events, and many part time residents were in the area.	Small number of participants.	Events during other times of the year could have been used for recruitment.
Rural Lifestyle	Many residents were involved in previous NOWTS events.	Small number of participants.	Many residents came to La Pine to be "left alone" or are on vacation.
Meeting Time and Location	• Friday at 5 pm at La Pine Senior Center. • Centrally located. • Location of other public meetings. • People who worked 8 am -5 pm.	Senior Center closes at 4 pm, looked vacant at meeting time. Some people drive by without stopping.	• Table was placed outside front door of senior center with study materials. • IWW sign with OSU logo was prominently displayed.
Solar Eclipse	Focus group scheduled 3 days before eclipse, expected business as usual.	• Solar Eclipse 2017, La Pine near path of totality. • High traffic and shortages on day of focus group.	Unpredictable
Dress	Street clothes were worn because previous experts were seen as 'arrogant.'	Participants were unable to recognize the researcher.	Business casual was adopted for rest of study.
People	Stakeholders were highly organized and were adept at planning events.	Organization was difficult because many stakeholders who were involved had other priorities.	• Flexible activities and times. • Activities which do not require in person meetings. • Schedule activities without participant input. • Shorter and more activity times.
Fatigue	• Stakeholders were highly active at 2015 Goal 11 exception events. • Stakeholders were involved in NOWTS issues for decades.	• By 2017, substantive regulations had failed to pass. • Regulators were not taking action. • Lack of funding.	Longer recruitment periods with more stakeholder interaction to increase interest.

B5.3.3 Interviews in Laramie

Many groups were not included in this study because they declined to be interviewed due to the author's connection to CAP Network, due to legal reasons, or because they viewed themselves as not involved in CAPA conflicts.

When comparing the surveys in La Pine to the interviews in Laramie, the latter were more successful because:

- Answers to open-ended questions used in interviews were more detailed.
- Interviews increased the interaction and familiarity between interviewer and participants.
- Social cues and body language were communicated.
- Miscommunications were addressed immediately to assuage conflict.
- Interviewer has greater control over data quality by knowing who was interviewed and by being able to ask clarifying questions.

B6. Conclusion

This study explored the effects of the structure and history of conflicts over nitrate contamination from onsite wastewater treatment systems (NOWTS) in La Pine, OR and Laramie, WY on the policies and studies used to address NOWTS.

The following conclusions are based on surveys, interviews, and documents on the NOWTS conflicts in La Pine and Laramie.

- Stakeholders were split based on the urban-rural divide in both La Pine and Laramie. Though there were differences in the structure of the divide, rural groups in both areas shared similar values.
- Arguments used by stakeholders in Laramie focused more on geology, while in La Pine they focused more on the impacts on human health. This could be because the geology of both areas is well understood, but the geological stratigraphy in Laramie is better defined than in La Pine.
- Stakeholders became more knowledgeable as they participated in conflicts. Knowledgeable stakeholders also became more politically savvy. Because knowledge was not standardized, stakeholders had more conflicting views of NOWTS.

- Stakeholders and experts formed opinions of other stakeholders based on their history of interactions. These opinions set the tone for future interactions that tended to reinforce existing opinions.
- Stakeholders in La Pine and Laramie felt some form of fatigue when addressing the decades-long NOWTS conflict. Signs of fatigue ranged from being less active in the conflict to frustration over stakeholders or issues.

B6.1 Policy Recommendations

The conflicts in La Pine and Laramie are continuing even at the time of this study. Since the situation is constantly shifting and to avoid having this study go quickly out of date, this study provides more general policy recommendations.

Policy recommendations are often a source of conflict in La Pine and Laramie. These recommendations were created in the hope that they would be less controversial.

Stakeholder groups can enlarge the scale of the issues they are working on, as was seen in Laramie, where NOWTS fell under the wider conflict over aquifer protection. By enlarging the scale of issues, stakeholder groups can apply more resources to addressing issues and can keep stakeholder interest high (Karkkainen; Ostrom, 1990; Heikkila and Gerlak, 2005; Wolf et al., 2010). The scale of an issue can be enlarged by increasing the number of issues an individual group works on or by building a coalition between groups that work on different but related issues. While groups in La Pine and Laramie do work with other groups on a local and national scale, these efforts could be further expanded.

Joint projects or joint fact-finding can be used to build trust and collaboration between groups. Using this strategy, multiple stakeholder groups would work on smaller, less contentious projects to create “small wins.” These “small wins” would be used as part of a wider strategy to build trust between stakeholder groups and motivate future projects (O'Brien, 2012). There are multiple ongoing collaborative projects in Laramie that could be leveraged to build trust between stakeholders (Pilot Hill Project, 2019; Achs and Bendtsen, 2019).

Another example of possible joint projects would be for technical experts and the public to collaborate on finding information about specific topics. Projects do not have to be as extensive as a study but could include projects as small as reviewing the literature on a topic that is not well known to experts or stakeholders. In communication, there were many smaller topics on which stakeholders disagreed that could be broken down further to start the joint fact-finding process. For example, in La Pine, more information could be collected on the health effects of nitrate in drinking water.

Lastly, when measuring stakeholder perspectives, interviews were better than surveys for conflict assessment, since interviews gave researchers greater flexibility and increased interaction between stakeholders and the researcher.

B7. References

Albany County Clean Water Advocates (ACCWA), 2019, About Us – Albany County Clean Water Advocates: Albany County Clean Water Advocates, http://albanycountycleanwateradvocates.org/about/ (accessed April 2019).

Achs, J., 2019a, City Council gives initial OK to annexing land in aquifer protection zone: Laramie Boomerang 3 July, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/city-council-gives-initial-ok-to-annexing-land-in-aquifer/article_9eea7754-cd50-5aae-b47b-4c68b0ead5b2.html (accessed November 2019).

Achs, J., 2019b, City officials raise concerns about UW well drilling project: Laramie Boomerang 20 September, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/city-officials-raise-concerns-about-uw-well-drilling-project/article_d4345bdd-e9b6-5555-9de1-c390aeb7cfbd.html (accessed November 2019).

Achs, J., 2019c, City remains ‘actively concerned’ about I-80 diesel spill’s potential effect on aquifer: Laramie Boomerang 25 January, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/city-remains-actively-concerned-about-i--diesel-spill-s/article_55d2ed29-e418-54be-9763-e86e1404a1f0.html (accessed November 2019).

Achs, J., 2019d, County continues work updating hazard mitigation plan: Laramie Boomerang 2 July, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/county-continues-work-updating-hazard-mitigation-plan/article_9ffb8b60-135a-59ba-9642-d39f064e618e.html (accessed November 2019).

Achs, J., and Bendtsen, D., 2019, Officials hope aquifer study helps create better policies: Laramie Boomerang 29 June, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/officials-hope-aquifer-study-helps-create-better-policies/article_3e91486b-650c-5762-a978-cb040c5f7ead.html (accessed November 2019).

Ahola, S., 2017, Why (not) disagree? Human values and the readiness to question experts’ views: Public Understanding of Science, v. 26, p. 339–354, doi:10.1177/0963662516637818.

Albany County Planner, 2011, Casper Aquifer Protection Plan: Albany County, Wyoming, 132 p.

Ansell, C., and Gash, A., 2007, Collaborative Governance in Theory and Practice: Journal of Public Administration Research and Theory, v. 18, p. 543–571.

Athey, R.D., 2011, Albany County, Wyoming: I-80 Telephone Canyon: Casper Aquifer Protection Study: Trihydro Corporation, Albany County 161-002–001, 96 p.

Baumann, P., Haugen, S., Robertson, J., Black, D., and Kaltenbach, C., 2017, Land Purchase could be boon to county - if cost doesn’t kill it: Laramie Boomerang 23 July, Laramie, Wyoming.

Bendtsen, D., 2019a, County issues emergency ban on aquifer development: Laramie Boomerang 11 June, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/county-issues-emergency-ban-on-aquifer-development/article_94b00da8-6dc9-5430-877d-497f2c114795.html (accessed June 2019).

Bendtsen, D., 2019b, Homeowners petition for aquifer zone expansion: Laramie Boomerang 24 October, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/homeowners-petition-for-aquifer-zone-expansion/article_528b3c70-e227-5145-81e8-4ecd5c367fc4.html (accessed November 2019).

Benson, W., 2008, Commission spoiled La Pine home values: The Bulletin 13 Novemeber, Bend, Oregon, p. 2. https://www.bendbulletin.com/opinion/commission-spoiled-la-pine-home-values/article_132bdc36-2cbb-55e5-b129-c1d9540204a7.html.

Borrud, H., 2010, DEQ drops lawsuit defense: The Bulletin 12 December, Bend, Oregon, p. 2. https://www.bendbulletin.com/localstate/deq-drops-lawsuit-defense/article_6720e18c-8cf2-5f82-82d8-018df30a5ed3.html

Bulletin Editorial Board, 2018, Editorial: La Pine makes important change for clean water: The Bulletin 31 March, Bend, Oregon, http://www.bendbulletin.com/opinion/6126139-151/editorial-la-pine-makes-important-change-for-clean (accessed March 2019).

Burow, K.R., Nolan, B.T., Rupert, M.G., and Dubrovsky, N.M., 2010, Nitrate in Groundwater of the United States, 1991−2003: Environmental Science & Technology, v. 44, p. 4988–4997, doi:10.1021/es100546y.

Central Oregon LandWatch, 2019, Who We Are — Central Oregon LandWatch:, https://www.centraloregonlandwatch.org/who (accessed November 2019).

Chu, K., 2007, Newest Deschutes planners signaling growth slowdown: The Bulletin 20 January, Bend, Oregon, p. 5.

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area:

Cole, D.R., 2006, Groundwater Quality Report for the Deschutes Basin, Oregon:, 59 p.

Comly, H., 1945, Cyanosis in Infants Caused by Nitrates in Well Water: Journal of the American Medical Association, v. 129, p. 112–116.

Connelly, D.R., Zhang, J., and Faerman, S., 2008, The Paradoxical Nature of Collaboration, *in* Big Ideas in Collaborative Public Management, New York, NY, Sharpe, p. 17–35.

Daniels, S.E., and Walker, G.B., 2012, Lessons from the Trenches: Twenty Years of Using Systems Thinking in Natural Resource Conflict Situations: Systems

Thinking and Natural Resource Conflict: Systems Research and Behavioral Science, v. 29, p. 104–115, doi:10.1002/sres.2100.

Daniels, S.E., and Walker, G.B., 2001, Working through environmental conflict: the collaborative learning approach.: Westport, CT, USA, Praeger.

Deschutes County Community Development Department (DCCDD), 2007, Drinking Water Protection in South Deschutes County: Alternatives Analysis:

Deschutes County, 2019, South Deschutes County Groundwater Protection Project | Deschutes County Oregon: Deschutes County, https://www.deschutes.org/cd/page/south-deschutes-county-groundwater-protection-project (accessed January 2019).

Emerson, K., Nabatchi, T., and Balogh, S., 2012, An Integrative Framework for Collaborative Governance: Journal of Public Administration Research and Theory, v. 22, p. 1–29, doi:10.1093/jopart/mur011.

Fredregill, I., 2017, Casper Aquifer prohibited uses review; Environmental Advisory Committee to welcome new members, elect chair, vice-chair: Laramie Boomerang 3 January, Laramie, Wyoming. https://www.laramieboomerang.com/news/environmental-advisory-committee-to-welcome-new-members-elect-chair-vice-chair/article_a88a5ba0-d171-11e6-8b10-0b407369caaa.html

Funk, J., 2015, “A delicate balance”; Many divided over private development, aquifer protection: Laramie Boomerang 4 August, Laramie, Wyoming, p. 1, 3.

Funk, J., 2016a, Changes to Casper Aquifer Plan on Table; committee skeptical of allowing car dealership on Casper Aquifer: Laramie Boomerang 6 November, Laramie, Wyoming, p. 1,10.

Funk, J., 2016b, Mountain West approved: Laramie Boomerang 6 January, Laramie, Wyoming.

Gannet, M.W., and Lite, K.E., 2004, Simulation of Regional Ground-Water Flow in the Upper Deschutes Basin, Oregon: US Geological Survey Water-Resources Investigations Report Water-Resources Investigations Report 03-4195, 95 p.

Gillette, K., 2007, Don’t believe county’s nitrate claims: The Bulletin 6 April, Bend, Oregon, p. 3.

Groundwater Foundation, 2017, 2017 Groundwater Guardian Profiles: Groundwater Foundation, 70 p.

Haderlie, C., 2010, What's Polluting Our Water? Laramie Boomerang 7 August, Laramie, Wyoming, p. 1.

Hamway, S., 2018, $25M La Pine infrastructure project moves forward; Project to bring nearly 300 lots onto water, sewer system and expand capacity: The Bulletin 28 February, Bend, Oregon, https://www.bendbulletin.com/localstate/6120818-151/25m-la-pine-infrastructure-project-moves-forward (accessed April 2019).

Heikkila, T., and Gerlak, A.K., 2005, The Formation of Large-scale Collaborative Resource Management Institutions: Clarifying the Roles of Stakeholders, Science, and Institutions: Policy Studies Journal, v. 33, p. 583–612, doi:10.1111/j.1541-0072.2005.00134.x.

Hinckley, B., and Moody, C., 2015, Phase II - Laramie Monitor Well Project Report: City of Laramie, 145 p., https://www.cityoflaramie.org/DocumentCenter/View/8384/Phase-II-Report-final-complete (accessed February 2019).

Hinkle, S., Bohlke, J., and Fisher, L., 2008, Mass balance and isotope effects during nitrogen transport through septic tank systems with packed-bed (sand) filters: Science of The Total Environment, v. 407, p. 324–332, doi:10.1016/j.scitotenv.2008.08.036.

Hinkle, S.R., Morgan, D.S., Orzol, L.L., and Polette, D.J., 2007, Ground Water Redox Zonation near La Pine, Oregon: Relation to River Position within the Aquifer-Riparian Zone Continuum: US Geological Survey, Deschutes County Scientific Investigations Report 2007–5239, 38 p.

Hinkle, S.R., Weick, R.J., Johnson, J., Cahill, J.D., Smith, S.G., and Rich, B., 2005, Organic Wastewater Compounds, Pharmaceuticals, and Coliphage in Ground Water Receiving Discharge from Onsite Wastewater Treatment Systems near La Pine, Oregon: Occurrence and Implications for Transport.: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Environmental Health Division Scientific Investigations Report 2005–5055, 98 p.

Hofman, J., 2007, Septic Smiles: The Bulletin 7 January, Bend, Oregon, https://www.bendbulletin.com/opinion/septic-smiles/article_13f1a414-6d37-5ec6-8af7-566611781b84.html.

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Huxham, C., 2000, The Challenge of Collaborative Governance: Public Management: an International Journal of Research and Theory, v. 2, p. 337–357.

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

Karkkainen, B.C. Collaborative Ecosystem Governance: Scale, Complexity, and Dynamism:

LeClair, A., 2012, APOZ Amendments Approved: Laramie Boomerang 8 August, Laramie, Wyoming, https://www.laramieboomerang.com/news/apoz-amendments-approved/article_bec2dd4f-1881-5b70-98b6-0fc8f8bbc379.html.

Mandelker, D.R., 1976, The Role of the Local Comprehensive Plan in Land Use Regulation: Michigan Law Review, v. 74, p. 899–973, doi:10.2307/1287830.

Mast, T., 2014, Symbolic victory; Parks and Recreation Master Plan nixes symbols outside city: Laramie Boomerang 24 October, Laramie, Wyoming, p. 1.

Mast, T., 2016, UW study ready to test nitrate levels in creek, aquifer: Laramie Boomerang 2 April, Laramie, Wyoming, p. 1.

McLaren, A.D., 1976, Rate constants for nitrification and denitrification in soils: Radiation and Environmental Biophysics, v. 13, p. 43–48.

Miller, C., 2019, Miller: Hinckley's aquifer arguments lack merit: Laramie Boomerang 8 December, Laramie, Wyoming, https://www.laramieboomerang.com/opinion/guest_column/miller-hinckley-s-aquifer-arguments-lack-merit/article_90e4449b-68a0-5655-ba4e-4a5d9191dfb2.html (accessed December 2019).

Moore, C., 1986, The mediation process : practical strategies for resolving conflict: San Francisco, Jossey-Bass.

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Neary, B., 2012, Committee Shoots Down Laramie Aquifer Funding: Laramie Boomerang 24 February, Laramie, Wyoming, p. 1,5.

Newman, E., 2012, Measuring the cost; City's aquifer protection law balances business development with hazard reduction: Laramie Boomerang11 February, Laramie, Wyoming, p. 8.

Nielsen, J.L., 2016, Tooele-County-Septic-Density-Study-FINAL-00000002-5.pdf: Tooele County, Hansen Allen & Luce Inc. HAL Project No. 283.02.101, 46 p., http://tooelehealth.org/wp-content/uploads/2016/05/Tooele-County-Septic-Density-Study-FINAL-00000002-5.pdf (accessed February 2019).

Nigg, E., and Baggett, R., 2013, South Deschutes/North Klamath Groundwater Protection: Report and Recommendations: Oregon Department of Environmental Quality, 32 p.

O'Brien, M., 2012, Review of collaborative Governance: Factors Crucial to the internal workings of the collaborative process: New Zealand Ministry for the Environment Publication Number CR 135.

Ostrom, E., 1990, Governing the Commons: The Evolution of Institutions for Collective Action: Cambridge University Press.

Pedersen, D., 2015, Groundwater Quality Protection in Oregon: Oregon Department of Environmental Quality, 33 p.

Pilot Hill Project, 2019, The Pilot Hill Project: Pilot Hill Project, http://pilothill.org/ (accessed April 2019).

Pretty, J., 2003, Social Capital and the Collective Management of Resources: Science, v. 302, p. 1912–1914, doi:10.1126/science.1090847.

Raff, L., 2006, Sewer expansion nears finish: The Bulletin 30 January, Bend, Oregon, p. 2.

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Robson, C., 1993, Real World Research: A Resource for Social Scientist and Practitioner-Researchers: Blackwell.

Rogers, E., and Weber, E.P., 2010, Thinking Harder About Outcomes for Collaborative Governance Arrangements: The American Review of Public Administration, v. 40, p. 546–567, doi:10.1177/0275074009359024.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Ryan, Holstun, and Bassham, 2016, Before the Land Use Board of Appeals of the State of Oregon: Central Oregon Landwatch (petitioner), vs. Deschutes County (Respondent) and Oregon Department of Environmental Quality: v. LUBA No. 2016-020, p. 33.

Sabatier, P.A., Leach, W.D., Lubell, M., and Pelkey, N.W., 2005, Theoretical frameworks explaining partnership success, *in* Swimming Upstream:

Collaborative Approaches to Watershed Management, Cambridge, MA, MIT Press, p. 173–200.

Schroeder, P.E., Brandhuber, P., and Thompson, K., 2013, East Laramie Waste Water Feasibility Study:, http://albanycountycleanwateradvocates.org/wp-content/uploads/2017/11/item-13-report-link.pdf (accessed February 2019).

Shorack, T., 2014, Septic inspector vanishes allegedly with reports and fees: The Bulletin 6 December, Bend, Oregon, http://www.bendbulletin.com/localstate/deschutescounty/2657696153/septicinspectorvanishesallegedlywithreportsandfees.

Shumway, J., 2019, La Pine builder calls Deschutes County groundwater plan a failure: The Bulletin 11 April, Bend, Oregon, http://www.bendbulletin.com/localstate/7079886-151/builder-questions-deschutes-county-groundwater-plan (accessed October 2019).

Sirianni, C., 2010, Investing in Democracy: Washington DC, Brookings Institutions.

Starkey, K., 2008, Give credit where credit is due: Laramie Boomerang September 18, Laramie, Wyoming.

Starkey, R., 2017, Overview of the Casper Aquifer Protection Network Groundwater Sampling Program: presented to the Albany County Board of County Commissioners and to the Albany County Planning and Zoning Commission

Stollar, C., 2006, La Pine water plan raises doubts: The Bulletin 10 April, Bend, Oregon, p. 4.

The Bulletin, 2005, La Pine contractor gets state fine: The Bulletin 13 March, Bend, Oregon, http://www.bendbulletin.com/news/1489164153/lapine-contractor-gets-state-fine

The Bulletin, 2007, Fake warning signs removed in Sunriver: The Bulletin 19 May, Bend, Oregon, http://www.bendbulletin.com/news/1515499153/fake-warning-signs-removed-in-sunriver.

Thomson, A.M., Perry, J.L., and Miller, T.K., 2008, Linking Collaboration Processes and Outcomes, *in* Big Ideas in Collaborative Public Management, New York, NY, Sharpe, p. 24.

Tippin, C., 2014, Containment pond plan scuttled; Mountain Land and Cattle denies access for Casper Aquifer: Laramie Boomerang 5 July, Laramie, Wyoming, https://www.laramieboomerang.com/news/mountain-land-and-cattle-denies-access-for-casper-aquifer-protection-containment-pond/article_6a89cb52-cf23-59b7-9c6e-a9f9ac9bae4d.html.

Tippin, C., 2013a, Debating Trash Controls; County residents ask commissioner to overrule city trash ordinance: Laramie Boomerang 23 February, Laramie, Wyoming, p. 1.

Tippin, C., 2013b, Underground maps made from the sky; UW geophysics project to map aquifers in Laramie and Snowy ranges: Laramie Boomerang 13 September, Laramie, Wyoming.

Weber, E.P., 2013, Building Capacity for Collaborative Water Governance in Auckland: Auckland Council Water Management, 51 p.

Wenck Associates, 2019, Albany County Septic System Impact Analysis: Wenck Associates, Albany County, Wyoming Department of Environmental Quality, 269 p.

Wessel, C., Buzzone, J., Hummel, A., Daily, G., and Kropf, C., 2013, Strategies for Management of High-Density Septic System Developments in Washoe County:, http://documents.wrwc.us/files/Strategies%20for%20Managaement%20of%20High-Density%20Septic%20System%20Developments%20in%20Washoe%20County.pdf (accessed February 2019).

Williams, J.S., Morgan, D.S., and Hinkle, S.R., 2007, Questions and Answers About the Effects of Septic Systems on Water Quality in the La Pine Area, Oregon:

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

Wolf, A.T. et al., 2010, Sharing Water, Sharing Benefits; Working Towards Effective Transboundary Water Resources Management: United Nations Education, Scientific and Cultural Organization, 284 p.

Watershed Professionals Network, 2002, Little Deschutes River Subbasin Assessment: Upper Deschutes Watershed Council.

Appendix C

Science Communication, Miscommunication, and Conflict:

La Pine, OR and Laramie, WY

C1. Introduction

In La Pine, OR and Laramie, WY, the majority of rural residents treat their wastewater by using conventional septic systems. A minority of rural residents use other types of onsite wastewater treatment systems (OWTS) (septic systems are a type of OWTS). Wastewater is treated within septic systems and as wastewater infiltrates through the soil to groundwater. If the water is not completely treated in soils, it can contaminate groundwater used for drinking water (Appendix A).

In La Pine and Laramie, many stakeholders (for this study, the term *stakeholder* refers to anyone that has an interest in the issues, including experts) have been involved in the decades of conflict over the amount of nitrate from OWTS that contaminates groundwater and the appropriate regulatory response to potential contamination from OWTS (Appendix B).

One part of the conflict is disagreement between stakeholders (and experts) over how much nitrate from septic systems enters groundwater and the risk it poses to the community. Nitrate is a contaminant of concern because it has the potential to cause algal blooms in surface waters, and nitrate over 10 mg/L in drinking water can increase the potential for methemoglobinemia in infants, though it has little impact on older populations. Water quality in private wells is a legal grey area, as private wells are only regulated in certain areas, and enforcement measures in the Western US are often weak or voluntary.

Another component of the conflict is how government experts, academics, and consultants (GAC experts) communicate with stakeholders. *GAC experts* specifically refers to government experts, consultants, and academics, while the term expert applies to people or groups that have definitive knowledge of a topic.

GAC experts are involved and play multiple roles in political conflicts over environmental issues: the *pure scientist* who only looks at facts and has no political interactions, the *science arbiter* who answers specific stakeholder questions, the *issue advocate* who limits choices by advocating for a certain choice, or the *honest broker* who clarifies or expands the choices available (Pielke, 2007).

The roles experts play create communication issues between stakeholders and experts, such as the pure scientists' detachment from politics (Pielke, 2007). Other communication issues arise from the varied roles experts play in conflict:

- Experts can have multiple roles (including the role of stakeholder).
- Experts can change roles.
- Stakeholders can view experts as playing a different role than experts view themselves as playing (Pielke, 2007; Ahola, 2017).

An example of an expert changing roles would be if an expert was brought in as an honest broker on an environmental issue to analyze the issue and increase stakeholder certainty, easing the decision-making process (Ahola, 2017). The scientist could change to an issue advocate after their analysis if they started advocating for specific regulation or technologies as the "solution" to the issue.

Another communication issue that creates social distance between experts and stakeholders is the difficulties experts have in communicating the nuances of complex issues to people, including other experts in their own discipline (Ahola, 2017). Often stakeholders (including experts) have different knowledge bases and are trained to communicate differently (Lackey, 2004).

The purpose of this chapter is to add to the growing body of work on conflict and science communication, by showing how the conflicts in La Pine and Laramie were affected by the way GAC experts communicated with stakeholders. It is important to understand these communication issues in order to better manage environmental conflicts.

This study examines the impact of communication between GAC experts and stakeholders by analyzing case studies from La Pine, OR and Laramie, WY. Some of the GAC expert studies were highly controversial, while others were not. The author's intention for this study was to not personally attack any one group but rather to explore why these studies (including the author's own study) were so controversial.

C2. Methods

This study looks at controversial projects conducted by GAC experts in La Pine and Laramie. Though there were many less controversial projects, more controversial projects are studied because there is more information available on stakeholder interpretations of expert projects.

Case studies were created based on five controversial studies created by GAC experts in La Pine and Laramie. For La Pine, the chapter focuses on The La Pine National Demonstration Project (LPNDP) and Fate and Transport of Nitrate from Septic Systems (Appendix A). For Laramie, the chapter focuses on the 2008 update to the Casper Aquifer Protection Plan (2008 CAPP), the 2009/2010 Monitoring of the Casper Aquifer Protection Area (MCAPA), and the Albany County Septic System Impact Analysis (ACSSIA).

For each case study, a summary of the project is provided, followed by the stakeholder responses to the study. The stakeholder responses are based on surveys, interviews, and other communications (Appendix B). Where possible, information from the surveys and interviews was corroborated with local newspaper articles, journal articles, US Geological Survey reports, agency reports, consultant reports, city/county/non-governmental organization documents, laws, websites, and graduate theses.

Funding and in-kind services for this project were provided by Central Oregon LandWatch, CAG, and CAP Network.

C3. Results

C3.1 La Pine

Two case studies were reviewed in La Pine: the La Pine National Demonstration Project (LPNDP) and a soil study the author conducted in the La Pine Area (Appendix B). Out of the many studies, these two were chosen because the LPNDP was highly controversial and the second study (Appendix B) was highly impacted by political repercussions from the LPNDP. There were other studies in the area but they had less documented impact and were outside of the experience of the stakeholders who interacted with the author.

C3.1.1 La Pine National Demonstration Project

The La Pine National Demonstration Project (LPNDP) was conducted by the US Geological Survey (USGS), the Oregon Department of Environmental Quality (ODEQ), and Deschutes County. The LPNDP was motivated by concerns that

NOWTS was a growing issue because there were ~7,000 homes on septic systems in the La Pine Area. The population of Deschutes County also grew by 54% between 1990 and 2000 (Watershed Professionals Network, 2002; Rich, 2005). Wastewater treatment feasibility studies determined that using onsite wastewater treatment systems (OWTS) that treated for nitrate was the most feasible way to address wastewater issues.

The LPNDP was a large project that had many parts. Twelve types of OWTS were installed in homes and tested to determine how well the OWTS treated nitrate to form nitrogen gas (Hinkle et al., 2005, 2008; Rich, 2005). Hydrologic and contaminant transport models were created (Gannett et al., 2001; Morgan et al., 2007; Morgan, 2008) and policy options were developed to address potential NOWTS issues in La Pine (Rich, 2005; Morgan et al., 2007).

The work conducted at the LPNDP was presented nationally at conferences and locally to residents in the La Pine Area at public meetings (Rich, 2005; Stollar, 2006; Ramsayer, 2006; Clark, 2009). The results from the project were part of USGS, ODEQ, and Deschutes County reports (Hinkle et al., 2005, 2007b; Morgan et al., 2007) and were published in journals (Hinkle et al., 2007a, 2008). The LPNDP also had a webpage and a pamphlet (Williams et al., 2007).

The Deschutes County government took many actions based on the results of the LPNDP. Some of the less controversial actions were the county's creation of High Groundwater Areas, in which development was limited if the water table was less than 2 ft deep, and Deschutes County's Transferable Development Program, which requires developers to have credits to develop land. Credits could be acquired by helping land owners build nitrate-treating OWTS or by buying land easements so that land would not be developed. Deschutes County also provided financial assistance so land owners could construct nitrate-treating OWTS.

Multiple controversial governmental actions were later rescinded due to outcry by residents. In 2008, the Deschutes County Board of County Commissioners passed Ordinance 2008-012 and Resolution 2008-021, which would have required all residents to use nitrate-treating OWTS by 2022. The Ordinances were rescinded by a special election in 2009. After the county Ordinance 2008-021 was rescinded, the ODEQ created a steering committee, comprised of residents of the La Pine Area, to find a viable solution to NOWTS (Nigg and Baggett, 2013).

Based on the recommendations of the steering committee, a Goal 11 exception was passed in 2015 which would have allowed the construction of sewer and clustered wastewater treatment in rural communities. The Goal 11 Exception was remanded in 2016 by the Land Use Board of Appeals (LUBA) after *Central Oregon Landwatch (petitioner), vs. Deschutes County (Respondent) and Oregon Department of Environmental Quality* (Ryan et al., 2016).

Stakeholders disagreed with the expert findings and methods used in the LPNDP because:

- The data set included data from public water supplies and domestic wells, as opposed to dedicated monitoring wells.
- Data were included from monitoring wells near contaminant sources, such as wells near nurseries and leach fields, which may not be representative of the subbasin.

- Stakeholders viewed wells with high nitrate values as outliers that skewed the data in the model.
- Stakeholders also mentioned that the nitrate concentrations did not appear to be increasing, as predicted in some of the USGS worst case scenarios.
- Stakeholders wanted a more in-depth peer review of the USGS studies and model.
- Many residents did not see the deterioration of water quality or health that was predicted in USGS models.
(Huddle, 2012)

At public meetings with experts, residents of the La Pine area were often aggravated by the way information was presented to them. At meetings, experts either presented information or answered questions posed by stakeholders (Rich, 2005; Clark, 2009). Stakeholders felt that experts expressed too much confidence in their views and spoke condescendingly to residents, and as a result, stakeholders perceived experts as arrogant (Hofman, 2007). Stakeholders also felt that they had little input in how the project was conducted.

The experts from the studies were used by governments as issue advocates after the study. Materials from the studies were often presented with proposed regulations so as to associate feelings about the regulations with the experts. Some of the regulations, especially Ordinance 2008-021, were shocking to stakeholders because the proposed regulations placed a financial burden on residents. The residents had an immediate emotional stress response to the proposed regulations, which was expressed as stakeholders viewing regulators as arbitrary, personally attacking residents, or corrupt, based on who benefitted from the regulations (Stollar, 2006; Hofman, 2007; Wolf et al., 2010).

Stakeholders viewed experts as being highly certain that nitrate was going to be an "emergency" issue for the La Pine Area, based on trends modeled for the area and language used by experts (Morgan et al., 2007; Hofman, 2007). Pamphlets on the studies presented worst case scenarios without showing the model of current conditions (Williams et al., 2007). The model and sense of urgency projected by regulators and experts conflicted with the experience of residents who had not had any negative impact from nitrate contamination (Ramsayer, 2006).

When experts communicated the health risks of nitrates in drinking water, they were often limited to saying that nitrates can cause blue baby syndrome, without going into further detail (Morgan et al., 2007). Because the information experts provided did not or could not communicate the complexity of NOWTS, residents often found information on their own. This led to conflicts because both experts and stakeholders had partial information, and the parts each group had could be viewed as contradictory (Stollar, 2006; Ramsayer, 2006; Gillette, 2007).

C3.1.2 Fate and Transport of Nitrate from Septic Systems: La Pine, OR

The Deschutes County Citizen's Action Group (CAG) reached out to the author to have a third party create a study that was independent from the LPNDP. The author analyzed nitrate in soils at a residence with a septic system and in undeveloped areas of La Pine. Simulations were then created for nitrate transport through soils underneath septic systems (Appendix B).

Many aspects of the study (Appendix B) were affected by the controversy over the LPNDP. The study was motivated by a citizen's action group who wanted a third party to conduct a study on NOWTS in the La Pine Area. The group wanted a study of the area but mistrusted the previous government experts who had studied the area.

The author came into conflict with the state government during the planning stages of the project due to a perceived funding conflict between the agency and the proposed project. A compromise solution was found for this conflict. After the study had been completed and the report had been delivered, there was little to no government response.

In an attempt to make the study (Appendix A) less controversial to residents in the La Pine Area, a second part was added to the study in which stakeholders participated in a focus groups and participated in sample collection. Participants were given surveys to determine their views on the NOWTS conflict and the soil study.

The author was in communication with stakeholders in the La Pine Area throughout the duration of the study. The author attended a citizen’s action group meeting and personally met with community members. After the study had been conducted, a report was given to stakeholders who had participated in the study or who had asked for a copy of the results.

The author attempted to avoid some communication barriers experienced with other studies but ran into a different set of communication barriers:

- The author was unfamiliar with communicating with stakeholders.
- The author dressed and acted casually, which made it difficult for stakeholders to identify the author as an expert and take the author seriously.
- Stakeholders were fatigued by decades of conflict over NOWTS.
- Including stakeholders in the project increased the complexity and time taken for the study.

These communication barriers are explained in more detail in Appendix B.

Other aspects of the project affected by previous political conflicts over the LPNDP include the location of the field site and the methods used for the study.

The way stakeholders viewed the study changed over the course of the study. During the planning stages, stakeholders who had been involved in NOWTS issues were engaged with the study, providing funding, material support, and advising on the study design. As the study progressed, new stakeholders who participated in the study also became engaged in the study because they had been directly affected by the NOWTS conflict. Even though some new participants were brought in, the total number of participants in the study was low. This was likely due to the practices used by the author and to stakeholder fatigue.

After the study was competed and the report was submitted, many stakeholders with whom the author worked were willing to work on future projects with the author and give access to their property for studies. The citizen's action group the author worked with also provided funding for future work.

C3.2 Laramie

Three contentious projects were reviewed in Laramie. The first was the 2008 update to the Casper Aquifer Protection Plan (CAPP; WHPA, 2008). The second was well water sampling conducted by the City of Laramie in the subdivisions east of Laramie (City of Laramie, 2010). The last project was a study of denitrification beneath a septic system (Wenck Associates, 2019).

C3.2.1 2008 Update to the Casper Aquifer Protection Plan

The Casper Aquifer Protection Plan (CAPP) was created in 2002 “to reduce the possibility of contamination to the Casper Aquifer.” Although the CAPP is not a legally binding document, the City of Laramie and Albany County have created local ordinances based on it.

The 2002 CAPP was created by a mix of government staff, local stakeholders, and local experts who volunteered to create the plan. The City of Laramie and Albany County hired the consulting firm Wittman Hydro Planning Associates (WHPA, a planning consulting firm from Indiana) to review and update the CAPP in 2007 (WHPA, 2008).

WHPA updated the CAPP based on updated geological information for the area and by consulting with local hydrogeologists, government staff, a technical advisory committee, the environmental advisory committee, and stakeholders. The 2002 CAPP also won an award at a planning conference.

When creating the CAPP, WHPA communicated individually with people and held working group meetings. The changes WHPA made were presented at working group meetings and in the CAPP document (Starkey, 2008).

Due to the way the CAPP was presented to stakeholders, there are many different interpretations of it. Private well owners disagreed with the 2008 update to the CAPP because it overrode the work and the CAPP created by community members in 2007 (Starkey, 2008).

Some of the recommendations in the 2008 CAPP were controversial. In the initial drafts of the 2008 CAPP, it was recommended that private well owners should stop using septic systems. In the view of some stakeholders, the recommendation was unreasonable because it was costly and septic systems were not viewed as a threat to groundwater.

Another controversial recommendation was to change the boundaries of the Casper Aquifer Protection Area (CAPA) to align with political boundaries instead of boundaries based on the geological structure of the area. The CAPA was a geographic area in which land uses were limited to protect the aquifer and was based on where the Satanka Shale was 75 ft thick or greater (WHPA, 2008). The new boundaries increased the size of the CAPA to account for new geologic information. Since lots were political and not geological, there were fewer lots that were split by the CAPA boundary, which would have placed them in a legal grey area. This change was opposed because it expanded the area that would be regulated and because it was not based on the geology of the area like the previous boundary had been.

The 2008 CAPP was written in passive voice using long sentences and ambiguous language. The writing was vague, so there were many different interpretations of the 2008 CAPP. The writing style use by WHPA was encouraged at the time the 2008 CAPP was written (Strunk and White, 2000). Since then the American Planning Association has changed the writing style guidelines for planning documents to plain English, which uses active voice and concise sentences to be more understandable (Noble, 2015).

One example of how the wording of 2008 CAPA could be interpreted differently by different stakeholders is the sentence, "Significant technical changes to the delineation of the Casper Aquifer Protection Area boundaries will be reviewed and approved by three Wyoming licensed professional engineers or geologists." The private well owners interviewed viewed the CAPP as a document that would be used to change regulations they would be forced to follow and believed that more evidence was needed to justify regulatory changes. Private well owners viewed the statement as WHPA stating that they would have the 2008 CAPP reviewed by licensed geologists. Based on this interpretation, WHPA was setting geologic boundaries without having a licensed engineer or geologist on staff. A stakeholder notified the Wyoming Board of Professional Geologists (WBPG) that WHPA was conducting geology without a license. The WBPG made the determination that WHPA was conducting geology without a license and sent WHPA a cease and desist letter.

The City of Laramie residents (and experts) interviewed interpreted the CAPP as an advisory document for potential policy actions which would be approved and completed by other groups. City residents interpreted the 2008 CAPP statement as saying that it was not the responsibility of WHPA to take actions based on the 2008 CAPP, and instead, the city and county government was responsible for approving and taking actions based on the 2008 CAPP. Based on this interpretation, WHPA was not guilty of practicing geology without a license. The urban residents interviewed supported the changes to the CAPA and the 2008 CAPP. Three local certified geologists reviewed the CAPP and wrote letters in support of the document.

Stakeholders sent another complaint to the WBPG because the geologists were paid by WHPA, which was viewed as a conflict of interest. Citizens for Clean Water lobbied against the Wyoming Board of Professional Geologist determination that WHPA was conducting geology without a license.

Government response to the CAPP was divided along the same lines as the responses of the stakeholders. The City of Laramie accepted the CAPP and updated city ordinances to include changes made by WHPA to the CAPP in 2008. Albany County did not accept the WHPA CAPP and created their own in 2011 (Albany County Planner, 2011), creating regulations based on the 2011 CAPP in 2012 (LeClair, 2012).

There was also a physical distance component to the controversy in that WHPA was based in Indiana and was acquired by a Texas company the same month the CAPP was submitted to the City of Laramie (Scranton Gillette Communications, 2008). After their involvement in the CAPP, WHPA became less aware of stakeholder perceptions of the 2008 CAPP because they were not physically present in Laramie. Stakeholders in Laramie were less likely to reach out to WHPA with their concerns with the 2008 CAPP because the city government was responsible for making decisions after the CAPP was submitted.

C3.2.2 2009/2010 Monitoring in the Casper Aquifer Protection Area

One of the projects recommended in the 2008 CAPP was increased groundwater monitoring of the CAPA. In 2009, the City of Laramie sampled 98 private wells in the CAPA for nitrate, approximately 20% of the residences in the

CAPA. The City of Laramie did not have the resources to conduct all the monitoring efforts suggested in the 2008 CAPP, but it was able to test private wells by cooperating with the Wyoming Department of Agriculture Laboratory (City of Laramie, 2010).

Letters explaining the MCAPA were sent to well owners, asking permission to test their wells before sampling, and individual results were reported to well owners. The results of the MCAPA were presented at public meetings, and a report was disseminated. The local newspaper reported on the results of the MCAPA (Haderlie, 2009). Three of the 98 wells were found to have nitrate concentrations over 10 mg/L. The MCAPA also noted that many of the wells were older or had no construction record, including some of the wells with over 10 mg/L of nitrate. The MCAPA report attributed the high nitrate concentrations of the wells to septic systems (City of Laramie, 2010).

Private well owners—some of whom were professors, geologists, and engineers—took issue with the reporting of the city water monitoring results:

- From interviews, there was increasing mistrust between rural residents and city government due to conflicts over the CAPP.
- From interviews, some residents had emotional responses to the study, including viewing it as a personal attack or as making them the scapegoat for contamination of the Casper Aquifer. This view was intensified by the depiction of the project in local news with the headline “Nitrate Levels in Well Water Unsafe” (Haderlie, 2010a).
- Private well owners felt that there was not enough evidence supporting the statements in the report attributing nitrate to septic systems. Private well owners connected the nitrate to other nitrate sources, including historic livestock grazing, natural conditions, and nitrogen fixation from plants.
- The subdivision with the highest nitrate concentrations was older and had old wells and septic systems that had not been maintained or had not been built to current construction standards.

- Some wells with elevated nitrate concentration had no septic systems that were up gradient of the wells.
- Many of the older wells had no existing documentation. Because some of the wells were not sealed, contamination from the surface could flow along well casings to contaminate groundwater. Some of the well casings were steel, which could have rusted.
- Rural residents wanted more sampling over time to confirm results from initial sampling in 2009 and to determine whether there were historic trends.

Due to these conflicts, the City of Laramie could not test private wells in future studies because of the heightened mistrust between private well owners and the city ,which meant that well owners would not grant the city access to their wells. In later projects, the city installed and tested monitoring wells instead of private wells (Hinckley and Moody, 2015). Private well owners also started conducting their own nitrate sampling in the CAPA. The group CAP Network initially conducted quarterly and subsequently annual water sampling from wells in the CAPA. The CAP Network also conducted a study on nitrate concentrations in a private well that had been replaced with a new sealed well that showed a reduction in nitrate concentrations (Starkey, 2017). A science fair project showed that nitrate from nitrogen fixation associated with native plants may be a source of nitrate in groundwater (Rovani, 2012). More information on these projects is provided in Appendix D.

The city residents interviewed agreed with the city project's assertion that septic systems were a source of nitrate. City residents interviewed viewed the reduction in private well owner participation in the study as a sign of the growing mistrust rural residents had of the City of Laramie.

No direct evidence was found of the impacts of the 2009/2010 monitoring program on Albany County government, though there are actions that might have been related to it. The 2009/2010 monitoring could be related to a part of the 2012 Albany County CAPP regulations (Aquifer Protection Overlay Zone) that included investigation exemptions for residential areas. Also, when the county studied nitrate from septic systems, the county focused on how much nitrate from septic systems was denitrified in unsaturated soils, instead of groundwater studies using wells. (Wenck Associates, 2019).

C3.2.3 Albany County Septic System Impact Analysis

In 2017, Albany County received funds from the Wyoming Department of Environmental Quality (WYDEQ) and matching funds from the county and City of Laramie for a project to determine how much nitrate was removed from wastewater as it infiltrated through the soil, through Quaternary unconsolidated alluvium, and through a portion of unsaturated Casper Formation (the geologic formation that contains the Casper Aquifer). Wenck Associates was hired to conduct the study (Wenck Associates, 2019). One of the county's goals was to use the study to make land use regulations that set minimum lot sizes in rural areas to safely distribute nitrate from septic systems (Walker, 2017a, 2017b).

In 2018, the study was set up at a residence on the CAPA east of Laramie. Lysimeters were placed from 5 ft to 35 ft beneath the leach field of a septic system to collect soil water samples. The holes into which the lysimeters were placed were drilled diagonally so as not to directly impact the septic system. A boring and soil samples were also collected near the leach field. Samples were collected between February and September from the septic system and lysimeters. The conclusion from the study was that nitrate in wastewater decreased from 69-91 mg/L to 51-56 mg/L as wastewater infiltrated trough soils. The treated wastewater was above public drinking water standards by the time it reached the geologic formation which contains the Casper Aquifer (Wenck Associates, 2019).

Wenck sent its report to the Wyoming Department of Environmental Quality for approval (Wenck Associates, 2019), and the results were presented to City of Laramie and Albany County officials at a public meeting in 2019 (Wenck Associates, 2019; Achs, 2019).

Wenck intentionally communicated less with the public before the study was completed. When the author approached Wenck in 2018 for an interview, Wenck stated that they were advised by the county to not talk about the Wenck study until after it was completed. Wenck also did not provide the report to county government officials or stakeholders for review until it was orally presented, so there was little time for stakeholders to prepare questions and voice concerns.

Interviews of stakeholders while the study was in progress showed that stakeholders had mixed feelings about the study. Interviewed experts (who were residents of the City of Laramie) were concerned that the study only sampled at one location and felt that Albany County officials were attempting to lessen the impact of the study. The county officials interviewed were concerned that the study only sampled at one location, and they were also concerned by the methods used.

The project was presented to the public using a technical format, though there were times when the expert who presented spoke with certainty which can be viewed as issue advocacy: "The bottom line is the unsaturated soil at the site is really not doing enough to protect the Casper Formation…" At other times, the presenter took a step back to be more like an honest broker, saying it was "ultimately up to the government" (Achs, 2019).

The Wenck presentation and report provided information in longer detailed format that took stakeholders and experts longer to digest. This communication format protected Wenck scientifically and legally but was not helpful for decision-makers. One decision-maker felt "paralysis by analysis" at the Wenck presentation (Achs, 2019).

People (experts and stakeholders) can only process information at a certain rate (Kobayashi, 1979). When people are not given enough time to process information, they remember the parts that are of greatest concern to them (Murata, 1997). This created different interpretations of the results of the Wenck study.

Conflict over the project became apparent during a conflict over zoning changes for a gas station in the CAPA. One expert (who was also a private well owner) believed that the study was compromised because the wastewater from the septic system could have potentially flowed down the casing of the borings for the lysimeters, thereby increasing the nitrate concentrations at depth. Wenck also accidentally drilled through a leach field, which was later back filled with native material (Starkey, 2020).

Wenck had a closer connection to Laramie than WHPA did because they were located closer to Laramie, and some Wenck employees had previously lived in

Laramie. Because Wenck had local connections, they were notified of stakeholder and expert disagreements with their project, later responding in a letter to the local newspaper (Stacy and Lidstone, 2019).

Wenck responded to the criticisms by the expert who was a private well owner with a letter which was published in the local newspaper (Stacy and Lidstone, 2019). A staff member from the Albany County Planning Department, geologists who were city residents, and residents from rural subdivisions outside of Laramie spoke in support of the ACSSIA (Thyne, 2019; Bendtsen, 2019; Moody, 2019). The CAP Network criticized the Wenck study in a newsletter submitted to CAP Network members and friends (Starkey, 2020).

The gas station was eventually approved, but by the time this study was written, neither the City of Laramie nor Albany County had taken other action which could be directly connected to the ACSSIA.

C4. Discussion

In La Pine and Laramie, the majority of the scientific studies were not controversial. There was little conflict over these studies because they had little impact on stakeholders or because the findings were on topics about which there was more agreement (MacLeod and Sammel, 1982; Athey, 2011; Baird, 2016). The case studies in the results section are examples of studies that were more contentious in La Pine and Laramie.

There were many practices used by GAC experts that increased the probability that their studies would escalate conflicts. Many of these practices are part of standard science or engineering practices and were developed to avoid scientific misconduct and to avoid bias. While these practices work in a more professional or academic setting, often they are not as effective in a political setting.

The author spoke to some of the GAC experts in La Pine and Laramie about the conflicts. Many GAC experts saw themselves in some aspect as pure scientists, science arbiters, or honest brokers who provided unbiased and objective information to stakeholders. At the same time, many GAC experts and stakeholders felt as though "politics trampled science." For example, information that was viewed as objective by one GAC expert was not always seen as objective by stakeholders or other GAC experts due to scientific uncertainty and to stakeholder language used in political conflicts. Some GAC experts also took on the roles of issue advocates or stakeholders, depending on their connections to the conflict or their personal feelings, mixed with scientific neutrality and politics.

Another aspect of "politics trampling science" was the ambiguity of the roles experts played, since experts changed their roles in the conflicts or experts viewed their roles differently than stakeholders did. This was seen in La Pine, where the USGS was brought in as a pure scientist or honest broker (Gannett et al., 2001; Hinkle et al., 2007b) but was viewed as an issue advocate when discussing potential regulations (Ramsayer, 2006). At the meetings, regulators explained that there was an "emergency" and that there were conflicts over the uncertainty of the studies and how much was "theory" (Ramsayer, 2006). In Laramie, local experts were both professional geologists and hydrogeologists, and at the same time they were residents who were part of community groups that advocated on issues.

Experts often physically present their work to stakeholders (at public meetings, panels, and other events) in a formal and technical manner. This often involves the expert standing at a podium, presenting slides to stakeholders in a dark room. This style of presentation creates a separation between experts and stakeholders, and stakeholders can view the experts as "arrogant." Conversely, this presentation format also places a social pressure on experts, in that the experts are the focus of attention and have to communicate or defend their work to stakeholders and government officials (Wolf et al., 2010).

In communication with experts in La Pine and Laramie, they were proud that they had undergone years of training on their subject of expertise and then spent many months doing the best job they could do on a project. These experts expressed frustration when their work was not accepted by stakeholders.

For example, experts in La Pine mentioned that nitrates cause blue baby syndrome. Stakeholders communicated their disagreement with the expert statement, since there were stakeholders who had blue baby syndrome that was unrelated to nitrate. The fact that nitrates can cause blue baby syndrome is the basis for nitrate regulations and is referenced in many nitrate studies (US EPA, 2015). These different interpretations of blue baby syndrome can be viewed as conflicting, even though both views are true. Blue baby syndrome is a symptom that can be caused by many different health issues, one of which is methemoglobinemia, which can be caused by nitrate (Cornblath and Hartmann, 1948; Thomson et al., 2008; Harper et al., 2017; Ahola, 2017).

Though it was only touched upon in communications with stakeholders and experts, some stakeholders and experts had different views of the presentations and other venues where experts shared information with the public. Some experts saw presentations and similar venues as a more academic setting, where objective information was shared. Some stakeholders, decision-makers, and experts, however, viewed presentations as political or legal arenas, where stakeholders were arguing over a specific political stance. This created conflict because the experts attempted to be politically neutral, whereas stakeholders were attempting to have experts support a political position.

When experts provide reports or present information from their studies, they often provide as much information as possible, for both scientific and legal reasons. However, providing too much information can fatigue stakeholders. This does not mean that stakeholders are not intelligent. At presentations, stakeholders have only hours or minutes to learn material that experts learned over months or years, while experts are attempting summarize information in a way that is understandable to stakeholders.

People (experts and stakeholders alike) can only process information at a certain rate (Kobayashi, 1979). When people were confronted with too much information to remember, they remembered the parts that were of greatest concern to them (Murata, 1997). Based on the parts that stakeholders remembered, the stakeholders and experts had different interpretations of a project. Providing more information also provided stakeholders with more information that could be contested.

In La Pine and Laramie, experts were brought in from outside of each community to study NOWTS as honest brokers (Morgan et al., 2007; WHPA, 2008). Initially outside experts were viewed as less biased because they did not have a history with the conflict. Later, due to the political conflict or undocumented stakeholder views, stakeholders and locals would often see outside experts as issue advocates, even when experts viewed themselves as unbiased and objective.

The outside experts often had much less interaction and history with stakeholders. Because they were thus less familiar with the conflict, they had a higher chance of touching upon politically contentious topics. For example, during the LPNDP, USGS simulations conflicted with local knowledge and the lived experience of residents.

Outside experts would have less interaction with the community after a project's completion than local experts, and it was up to decision-makers and other stakeholders to contact those outside experts or use their work. If their work had been critiqued or misinterpreted by stakeholders, outside experts were often not aware since stakeholders typically did not reach out to outside experts and outside experts did not check on stakeholders.

Local experts were viewed differently than outside experts because they had existing connections to the community. In communication with stakeholders, local experts in La Pine and Laramie were viewed by stakeholders as belonging to a "side" of the conflict. Stakeholders viewed experts on the same "side" as unbiased and trustworthy, whereas opposing experts were viewed as biased "scientist activists" (Clark and Illman, 2001).

In Laramie, stakeholders preferred local experts to outside experts for conducting studies and decision-making. Laramie was able to use local experts since there were many local water experts (Albany County Planner, 2011). In La Pine, by contrast, there were few local experts, so La Pine had to rely on outside experts. Nevertheless, there were many residents who were retired experts and critiqued studies that had been conducted by outside experts.

In the Nitrate Fate and Transport Study in La Pine, the author attempted to avoid some of the communication barriers between experts and stakeholders by wearing street clothes and speaking casually. This confused stakeholders because they could not differentiate or identify the author when they met the author for the first time. The casual style could have potentially decreased the impact of the studies because the author was viewed as not having the same level of expertise or professionalism as other experts.

There were many communication issues between GAC experts and stakeholders in La Pine and Laramie, as seen in the case studies (summarized in Table C1). These barriers both individually and in combination distanced GAC experts from stakeholders, increasing the chance that stakeholders and GAC experts would misinterpret each other and create conflict. These communication issues show that not only do GAC experts conduct studies but they are also responsible for communicating those studies to other people.

Table C1. Communication Issues between GAC Experts and Stakeholders

Communication Issues	Description
Ambiguous Expert Roles	The roles that GAC experts were expected to play were not clearly defined. GAC experts changed roles or had multiple roles at the same time. GAC experts were perceived by stakeholders as playing a different role than the role the experts thought they were playing.
Language	GAC experts presented their findings using passive voice, which made the information presented wordy and ambiguous. GAC experts who used active voice were seen as advocates or overconfident of their findings.
Mannerisms	GAC experts are expected to adhere to certain mannerisms and styles that can be perceived as talking down to stakeholders. Yet being too casual decreased the experts' credibility by breaking social norms.
Information Dumping	GAC experts often present findings in lengthy reports, presentations, and data sets, with little time for stakeholders to digest the material. While this protects experts scientifically and legally, more time is needed for experts and stakeholders alike to process information.
Study Limitations	All studies have weaknesses and limitations. Studies will not be able to address all stakeholder concerns, and many of the concerns will not be known until after the study, when stakeholders have had time to process the information.
External Factors	Many external factors affected the way stakeholders viewed experts, including existing conflict, stakeholder fatigue, undocumented stakeholder concerns, and experts' ability to understand the local context of conflicts.

C5. Conclusion

Stakeholders in La Pine and Laramie had the expectation that the work of scientists and engineers would aid them in gaining a clearer understanding of nitrate from onsite wastewater treatment systems (NOWTS). Contrary to stakeholder expectations, the works did not always provide clear answers and sometimes escalated political conflicts over NOWTS. The escalation of the conflict from scientist and engineers may or may not have been purposeful but was affected by many of the practices used by scientists and engineers to present their work to stakeholders.

There were many communication issues between GAC experts and stakeholders in the La Pine and Laramie conflicts over the issue of groundwater contamination by nitrate from septic systems. The communication issues included ambiguous expert roles, language, mannerisms, information dumping, study limitations, and external factors. Many of these communication issues result from the social norms and structures that GAC experts use to communicate with stakeholders and which are used to protect GAC experts legally and scientifically. These communication issues increased the chance that stakeholders and GAC experts would have conflicting interpretations of studies and information.

This chapter makes three policy recommendations based on the La Pine and Laramie case studies:

(1) Joint fact-finding by including stakeholders and stakeholder input more in research projects, or by reviewing information that is more uncertain and contentious to create a common pool of agreed upon information.
(2) A strategy that was suggested by GAC experts spoken to was to use simple long-term studies that directly addressed stakeholder concerns instead of more complex short-term studies.
(3) Concise communication using active voice and plain English (Reitter et al., 2011; Noble, 2015).

C6. References

Achs, J., 2019, Septic study shows elevated nitrates about Casper Aquifer, City discusses next steps: Laramie Boomerang 11 June, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/septic-study-shows-elevated-nitrates-about-casper-aquifer-city-discusses/article_1c40be77-ba4f-5ea7-a9cf-bb7e3d368e8f.html (accessed June 2019).

Ahola, S., 2017, Why (not) disagree? Human values and the readiness to question experts’ views: Public Understanding of Science, v. 26, p. 339–354, doi:10.1177/0963662516637818.

Albany County Planner, 2011, Casper Aquifer Protection Plan: Albany County, Wyoming, 132 p.

Athey, R.D., 2011, Albany County, Wyoming: I-80 Telephone Canyon: Casper Aquifer Protection Study: Trihydro Corporation, Albany County 161-002–001, 96 p.

Baird, B.D., 2016, City of La Pine, Oregon: Water System Study Update: City of La Pine, Anderson Perry & Associates Job No. 33-05.

Bendtsen, D., 2019, County planner says nitrate study was credible: Laramie Boomerang 21 December, Laramie, Wyoming, https://www.laramieboomerang.com/news/local_news/county-planner-says-nitrate-study-wascredible/article_a7e1616b-818d-526b-8536-c6b780c3c6a9.html

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area:

Clark, S., 2009, Notes, Questions and Answers from La Pine Community Meeting of July 22, 2009 and Follow-up to Further Questions:

Clark, F.A., and Illman, D.I., 2001, Dimensions of Civic Science: Science Communication, v. 23, p. 5–27.

Cornblath, M., and Hartmann, A.F., 1948, Methemoglobinemia in young infants: The Journal of Pediatrics, v. 33, p. 421–425, doi:10.1016/S0022-3476(48)80200-3.

Gannett, M.W., Lite, K.E., Morgan, D.S., and Collins, C.A., 2001, Ground-Water Hydrology of the Upper Deschutes Basin, Oregon: US Geological Survey, Oregon Water Resources Department, Cities of Bend, Redmond, Sisters, Deschutes and Jefferson Counties, The Confederated Tribes of the Warm Springs Reservation of Oregon, US EPA Water Resources Investigations Report 00–4162, 72 p., https://apps.wrd.state.or.us/apps/planning/owsci/view_project_image.aspx?project_type=GW&related_document_id=31 (accessed March 2019).

Gillette, K., 2007, Don’t believe county’s nitrate claims: The Bulletin 6 April, Bend, Oregon, p. 3.

Haderlie, C., 2009, City tests private wells: Laramie Boomerang 3 December, Laramie, Wyoming, https://www.laramieboomerang.com/news/city-tests-private-wells/article_0c8cfa05-c10f-5a44-8361-a01865f60a4f.html (accessed January 2020).

Haderlie, C., 2010a, Nitrate Levels in well water unsafe: Laramie Boomerang 14 July, Laramie, Wyoming. https://www.laramieboomerang.com/news/nitrate-levels-in-well-water-unsafe/article_67baf722-bac4-56e7-9e87-85db0bc5aacd.html

Haderlie, C., 2010b, What's Polluting Our Water?: Laramie Boomerang 7 August, Laramie, Wyoming, p. 1.

Harper, C. et al., 2017, Toxicological Profile for Nitrate and Nitrite: U.S. Department of Health and Human Services: Public Health Service: Agency for Toxic Substances and Disease Registry, p. 324.

Hinckley, B., and Moody, C., 2015, Phase II - Laramie Monitor Well Project Report: City of Laramie, 145 p., https://www.cityoflaramie.org/DocumentCenter/View/8384/Phase-II-Report-final-complete (accessed February 2019).

Hinkle, S.R., Böhlke, J.K., Duff, J.H., Morgan, D.S., and Weick, R.J., 2007a, Aquifer-scale controls on the distribution of nitrate and ammonium in ground water near La Pine, Oregon, USA: Journal of Hydrology, v. 333, p. 486–503, doi:10.1016/j.jhydrol.2006.09.013.

Hinkle, S., Bohlke, J., and Fisher, L., 2008, Mass balance and isotope effects during nitrogen transport through septic tank systems with packed-bed (sand) filters: Science of The Total Environment, v. 407, p. 324–332, doi:10.1016/j.scitotenv.2008.08.036.

Hinkle, S.R., Morgan, D.S., Orzol, L.L., and Polette, D.J., 2007b, Ground Water Redox Zonation near La Pine, Oregon: Relation to River Position within the Aquifer-Riparian Zone Continuum: US Geological Survey, Deschutes County Scientific Investigations Report 2007–5239, 38 p.

Hinkle, S.R., Weick, R.J., Johnson, J., Cahill, J.D., Smith, S.G., and Rich, B., 2005, Organic Wastewater Compounds, Pharmaceuticals, and Coliphage in Ground Water Receiving Discharge from Onsite Wastewater Treatment Systems near La Pine, Oregon: Occurrence and Implications for Transport.: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Environmental Health Division Scientific Investigations Report 2005–5055, 98 p.

Hofman, J., 2007, Septic Smiles: The Bulletin 7 January, Bend, Oregon, https://www.bendbulletin.com/opinion/septic-smiles/article_13f1a414-6d37-5ec6-8af7-566611781b84.html.

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

Kobayashi, S., 1979, Effects of Priority Instructions on Processing of Picture Items: Psychological Reports, v. 45, p. 919–922, doi:10.2466/pr0.1979.45.3.919.

Lackey, R.T., 2004, Normative Science: Fisheries, v. 29, p. 38–39.

LeClair, A., 2012, APOZ Amendments Approved: Laramie Boomerang 8 August, Laramie, Wyoming, https://www.laramieboomerang.com/news/apoz-amendments-approved/article_bec2dd4f-1881-5b70-98b6-0fc8f8bbc379.html.

MacLeod, N.S., and Sammel, E.A., 1982, Newberry volcano, Oregon: A Cascade Range geothermal prospect: Oregon Geology; Oregon Department of Geolgoy and Mineral Industries, v. 44, p. 123–131.

Moody, C., 2019, Moody: County officials should take study results seriously: Laramie Boomerang 29 December, Laramie, Wyoming, https://www.laramieboomerang.com/opinion/letters_to_editor/moody-county-officials-should-take-study-results-seriously/article_c8951f2d-6415-5ef8-b340-ce96f32351e0.html (accessed January 2020).

Morgan, D.S., 2008, South Deschutes County Ground Water Conditions:

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Deschutes County Scientific Investigations Report 2007–5237, 66 p.

Murata, A., 1997, On information dumping phenomenon in free recall - Effects of priority instructions on free recall of pictures and words: IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, v. E80-A, p. 1729–1731.

Nigg, E., and Baggett, R., 2013, South Deschutes/North Klamath Groundwater Protection: Report and Recommendations: Oregon Department of Environmental Quality, 32 p.

Noble, B.K., 2015, Zoning Codes in Plain English: Zoning Practice, American Planning Association, p. 8.

Pielke, R.A., 2007, The honest broker: Making sense of science in policy: Cambridge, UK, Cambridge University Press.

Ramsayer, K., 2006, Residents quiz geologists on La Pine water: The Bulletin 21 December, Bend, Oregon, p. 2.

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rittel, H.W.J., and Webber, M.M., 1973, Dilemmas in a General Theory of Planning: Policy Sciences, v. 4, p. 155–169.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Ryan, Holstun, and Bassham, 2016, Before the Land Use Board of Appeals of the State of Oregon: Central Oregon Landwatch (petitioner), vs. Deschutes County (Respondent) and Oregon Department of Environmental Quality: v. LUBA No. 2016-020, p. 33.

Scranton Gillette Communications, 2008, Layne Christensen Acquires Wittman Hydro Planning Associates: Water & Wastes Digest, https://www.wwdmag.com/layne-christensen-acquires-wittman-hydro-planning-associates (accessed January 2020).

Stacy, M., and Lidstone, C., 2019, Stacy/Lidstone: Hydrologists stand by work: Laramie Boomerang 21 December, Laramie, Wyoming, p. 3. https://www.laramieboomerang.com/opinion/guest_column/stacy-lidstone-hydrologists-stand-bywork/article_539f898b-31b1-556e-bf4b-021ecf994c4b.html

Starkey, K., 2008, Give credit where credit is due: Laramie Boomerang 18 September, Laramie, Wyoming.

Starkey, R., 2017, Overview of the Casper Aquifer Protection Network Groundwater Sampling Program:

Starkey, R., 2020, How Not to Conduct a Septic System Study and Issue Advocates versus Honest Brokers: CAP Network Newsletter,

Stollar, C., 2006, La Pine water plan raises doubts: The Bulletin 10 April, Bend, Oregon, p. 4.

Strunk, W., and White, E.B., 2000, Elements of Style: Pearson.

Thomson, A.M., Perry, J.L., and Miller, T.K., 2008, Linking Collaboration Processes and Outcomes, *in* Big Ideas in Collaborative Public Management, New York, NY, Sharpe, p. 24.

Thyne, G., 2019, Nitrate levels can be sourced to residential septic systems: Laramie Boomerang 15 December, Laramie, Wyoming, https://www.laramieboomerang.com/opinion/letters_to_editor/thyne-letter-nitrate-levels-can-be-sourced-to-residentialseptic/article_7c550caf-04c6-5f9e-97ba-8304af1e6c42.html.

US Environmental Protection Agency (US EPA), 2015, National Primary Drinking Water Regulations: US EPA, https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations (accessed October 2018).

Watershed Professionals Network, 2002, Little Deschutes River Subbasin Assessment: Upper Deschutes Watershed Council.

Walker, C., 2017a, Seeking more information on aquifer impacts; County Commission approves $30,000 grant to study septic systems on Casper Aquifer: Laramie Boomerang 22 September, Laramie, Wyoming, p. A1,A8.

Walker, C., 2017b, Studying the effects; County Commission plans study to measure pollutants in the Casper Aquifer: Laramie Boomerang 26 October, Laramie, Wyoming, p. 1, 10.

Wenck Associates, 2019, Albany County Septic System Impact Analysis: Wenck Associates, Albany County, Wyoming Department of Environmental Quality, 269 p.

Williams, J.S., Morgan, D.S., and Hinkle, S.R., 2007, Questions and Answers About the Effects of Septic Systems on Water Quality in the La Pine Area, Oregon:

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

Wolf, A.T. et al., 2010, Sharing Water, Sharing Benefits; Working Towards Effective Transboundary Water Resources Management: United Nations Education, Scientific and Cultural Organization, 284 p.

Appendix D

The Role of Resident Science in Conflicts over Nitrate from Septic Systems: La Pine, OR and Laramie, WY

D1. Introduction

There have been decades of political conflict in La Pine, OR and Laramie, WY over the environmental issue of groundwater contamination by nitrate from onsite wastewater treatment systems (NOWTS, pronounced 'knots'). NOWTS occurs when nitrate from septic systems (and other types of onsite wastewater treatment systems, or OWTS) contaminates groundwater that is used as a drinking water source. Nitrates are an environmental concern because nitrate can cause eutrophication in surface waters. Nitrates are also a health concern because nitrate increases the potential of methemoglobinemia in infants, though it has less impact on older populations (Gehle, 2013).

The Safe Drinking Water Act of 1974 limits nitrate to 10 mg/L, and in both La Pine and Laramie, over 95% of private wells had nitrate concentrations below the limits set for public drinking water supplies (Morgan et al., 2007; City of Laramie, 2010). Conflicts occurred because stakeholders held a spectrum of views, from nitrate being a large and growing problem to there being no contamination from OWTS. Stakeholder views were influenced by their financial, health, and environmental perspectives.

All stakeholders wanted regulation to protect groundwater, but they disagreed on the type of regulation, enforcement of regulations, and who would pay the cost of regulations (Appendix B). For this study, the term "stakeholder" refers to anyone with an interest in the political conflicts in La Pine and Laramie.

These conflicts were unique because scientific research that was conducted by non-governmental organizations, resident experts, or residents (resident science) was credible enough to be part of the discourse over NOWTS and to affect regulatory actions. In the Western US, the vast majority of scientific research on the subject has been conducted or funded by governments, based on a review of 51 communities with NOWTS issues (Appendix B).

The term “resident science” is used because science was conducted by stakeholders and experts in their capacity as residents of a community or community group, and the research was not affiliated with or funded by a government or academic institution. The term “citizen science” was not used because some of the projects were conducted by experts.

In previous studies, the acceptance of resident science has been mixed, and in some areas, resident science has little stakeholder credibility (Burch et al., 2010; Kurki, 2016). The effects of residents science on the views of stakeholders have been difficult to determine because data is qualitative, there are few long term studies, outcomes differ, and citizen attitudes shift (Nyerges et al., 2006; Bryer, 2009; Phillips et al., 2012)

The purpose of this study is to explore the role of resident science in conflicts in La Pine and Laramie, with a focus on (1) why stakeholders (and experts) created resident science and (2) why resident science was widely accepted among stakeholders (and local experts).

D2. Methods

The information about resident science was gathered from surveys, interviews, and communications the author had with stakeholders in La Pine and Laramie (Appendix B). Where possible, communications were corroborated with local newspaper articles, journal articles, US Geological Survey reports, agency reports, consultant reports, city/county/non-governmental organization documents, laws, websites, and academic graduate theses.

Case studies were created based on three resident science projects in La Pine and Laramie. In La Pine, the chapter analyzes *Groundwater Protection and the La Pine Basin*, conducted by the Deschutes County Citizen's Action Group (CAG) to review a study conducted by the US Geological Survey and analyze other publicly available information. CAG is a non-governmental organization (NGO) whose goals are "To preserve quality of life, protect individual and community rights, as well as to conserve rural identity and natural resources."

In Laramie, the study examines the Casper Aquifer Protection Network (CAP Network) Groundwater Sampling Program and a middle school science fair project (Jack and Jill Went Up the Hill to Fetch a Pail of… Nitrates!!!). The CAP Network is an NGO composed of over 200 private well owners who live east of Laramie, including some members who are water experts from the University of Wyoming or the community of local water consulting firms, as well as local government officials. Its mission is "to protect the Casper Aquifer and to preserve property rights for now and for the future" (CAP Network, 2011). The CAP Network activities include testifying and advocating at government meetings, outreach, education, newsletters, email notifications, and Casper Aquifer protection Area (CAPA) studies.

The results section summarizes each case study, exploring the background leading up to resident science, residents' motivation to take on the project, and the major conflicting perspectives on NOWTS held by stakeholders in La Pine and Laramie. The discussion synthesizes the case studies, focusing on why resident science was created and how resident science shaped policy.

The resident science case studies represent the resident science that was mentioned most often in interviews and other communication with stakeholders in La Pine and Laramie. Other resident science efforts were not included because they had less impact on stakeholders or information is unavailable. Resident science was difficult to find because it is often only used and stored by private groups and thus not published or publicly available.

Funding and in-kind services for this project were provided by Central Oregon LandWatch, CAG, and CAP Network.

D3. Results

The opinions expressed in the results section represent the views of stakeholders spoken to or interviewed in La Pine and Laramie and are not the author's personal opinions.

D3.1 La Pine

D3.1.1 *Groundwater Protection and the La Pine Basin*

Groundwater Protection and the La Pine Basin was a study conducted by members of the Deschutes County Citizen's Action Group (CAG), who analyzed publicly available data and results from the La Pine National Demonstration Project (LPNDP; Huddle, 2012). The LPNDP was a series of NOWTS-related projects in La Pine, conducted by Deschutes County and other government agencies between 1999 and 2007. The projects included studies of OWTS, hydrology, and nitrate contaminant transport (Rich, 2005).

CAG members distrusted LPNDP experts because the LPNDP findings did not agree with local knowledge, causing suspicion about the quality of the data analysis. LPNDP experts were viewed by residents as issue advocates because the regulations proposed by LPNDP experts were expensive and residents were expected to pay the cost. Finally, years after the LPNDP concluded, expert predictions of further groundwater contamination of groundwater did not come to pass. Through the whole process, government experts communicated poorly with stakeholders. Government expert communication is covered in more detail in Appendix C.

There were many residents of the La Pine area who were water professionals or had a PhD in a field of study not related to NOWTS, many of whom were retired (Stollar, 2006; Hofman, 2007). Educated residents associated with CAG reviewed the La Pine National Demonstration Project and conducted their own statistical analysis of the data from the LPNDP.

The residents disagreed with the way the LPNDP was conducted because:

- The data set included data from public water supplies and domestic wells, as opposed to dedicated monitoring wells.
- Data were included from monitoring wells near contaminant sources, such as wells near nurseries and leach fields, which may not be representative of the subbasin.
- Wells with high nitrate values were considered outliers, which skewed the data in the model.
- Many years after the LPNDP, nitrate concentrations did not appear to be increasing, as had been predicted in the 2139 simulation.
- Stakeholders wanted a more in-depth peer review of the USGS studies and model.
- There were no visible signs of deteriorating water quality or health issues from nitrates (Huddle, 2012).

One of the more controversial parts of the LPNDP was the models used to predict nitrate contamination from septic systems. Although the models of conditions in 1999 found higher nitrate levels than had been observed in well samples, the majority of residential areas had simulated nitrate concentrations below 5 mg/L. A simulation was created to predict nitrate in 2139 (130 years in the future) if the La Pine area was fully developed. In the 2139 simulation, nitrates in most residential areas exceeded 10 mg/L and in many areas were higher, at >20 mg/L. The 2139 model was controversial because it did not agree with stakeholder knowledge of the area.

The conflict over the LPNDP was most volatile when the Deschutes County Board of County Commissioners passed Ordinance 2008-012 and Resolution 2008-021, which required residents to use OWTS that could treat nitrate in groundwater. Residents of the La Pine Area opposed these regulations because the cost of installing OWTS placed a financial burden on stakeholders, and residents viewed the cost of regulations as greater than the risks posed by NOWTS. The ordinance and resolution were both rescinded in 2009 as a result of a special election (Nigg and Baggett, 2013).

Due to conflicts over the LPNDP, CAG created the resident science project *Groundwater Protection and the La Pine Basin*. Resident science was conducted by resident experts who were members of CAG. The resident experts had graduate educations (some related to water, others not) or had worked in water-related fields or for government agencies. Data from the LPNDP was reanalyzed and updated with new data on groundwater from other public sources.

La Pine Area residents had positive views of *Groundwater Protection and the La Pine Basin*, while state regulators had more neutral views of it.

Table C2. Views of *Groundwater Protection and the La Pine Basin* (Personal Communication)

Rural Residents (includes Experts)	State Regulator
La Pine area residents (the author spoke to or surveyed) liked the CAG project because it aligned with their knowledge and experience. Residents trusted CAG more than they trusted government experts.	State regulators' view of NOWTS changed over time as more data came out on the issue. Regulators were initially concerned by NOWTS in the 2000s (Ramsayer, 2006), but by 2017 they had stepped back as new information came out (Hammers, 2012). One regulator spoken to in 2017 saw the CAG project as validating the LPNDP, since the CAG findings agreed with the 1999 LPNDP simulation as well as with groundwater data collected after the LPNDP was published.

The views regulators had of NOWTS issues changed over time. Before the 2008 county ordinances, regulators and experts used language expressing their concern for NOWTS issues due to the rapid population growth in Deschutes County

(~54% between 1990 and 2000) and the findings of the LPNDP (Ramsayer, 2006). By 2012, regulators had toned down their rhetoric as a new round of monitoring well sampling of was conducted. The results of the 2012 well sampling showed little change in nitrate concentrations in two thirds of the wells, and few conclusions could be drawn as to whether nitrate concentrations were increasing or decreasing (Hammers, 2012).

One regulator spoken to at the time of this study in 2017 had a nuanced view of the studies conducted by government agencies but viewed the CAG analysis more as corroborating than conflicting with government studies.

In regulators' views, the parts of the studies that support each other were the CAG analysis and the LPNDP model based on conditions in 1999. While the LPNDP and CAG analysis gave different results, the differences were not large enough to be significant. The regulators placed less importance on the LPNDP scenarios that predicted conditions in 2139 because the conditions that the scenarios were based on had not occurred. Many of the weaknesses CAG saw in the LPNDP were noted in reports for the LPNDP but were in more technical language or were only covered briefly (Morgan et al., 2007).

Prior to their disbanding in 2019, CAG used *Groundwater Protection and the La Pine Basin* to explain their perspective of NOWTS to stakeholders.

D3.2 Laramie

In Laramie, the Casper Aquifer Protection Area (CAPA) was created to protect groundwater quality for the Casper Aquifer, which provides ~60% of the City of Laramie's water and 100% of the water for rural residents who live in the CAPA. The document that was used as the basis for regulations on the CAPA is the Casper Aquifer Protection Plan (CAPP). While the CAPP was not legally binding, it nonetheless served as the basis for city and county regulations to protect the Casper Aquifer. The first CAPP, in 2002, was created by local experts and stakeholders in the City of Laramie and Albany County.

Conflicts over the CAPA shifted to septic systems used by rural residents in the CAPA in 2006, when City of Laramie residents opposed construction of a rural subdivision in the CAPA and a moratorium was placed on construction. The subdivision was proposed by the University of Wyoming (UW) Golf Course. The consulting firm Wittman Hydro Planning Associates (WHPA) was hired by the City of Laramie to review and update the CAPP in 2007. The 2008 WHPA update to the CAPP was highly controversial in the Laramie area because it overrode a CAPP created by stakeholders in Laramie (Starkey, 2008), expanded the western boundaries, and recommended the expansion of sewer systems into rural subdivisions, which would have been costly to private well owners.

One suggestion of the 2008 CAPP was for more groundwater monitoring of public and private wells in the CAPA (WHPA, 2008). Based on this suggestion, the City of Laramie sampled private wells in the CAPA in 2009 and 2010 (City of Laramie, 2010), and a sewer feasibility study was conducted in 2013 (Schroeder et al., 2013).

D3.2.1 CAP Network Groundwater Sampling Program

Some private well owners in the CAPA who were University of Wyoming professors, geologists, and engineers disagreed with the 2009/2010 City of Laramie well sampling results because:

- There was existing mistrust between private well owners and the City of Laramie from previous city regulations (Appendix C and B).
- The city well sampling project concluded that nitrate came from septic systems owned by private well owners (City of Laramie, 2010). Private well owners disagreed because the nitrate could be from other sources — livestock, natural nitrogen fixation, and poorly constructed or maintained wells and septic systems.
- Private well owners wanted to determine for themselves the extent of nitrate impacts. The city was viewed as an issue advocate, since the city sampling could be used by the city to regulate private well owners.
- Private well owners believed more sampling over time was necessary in order to confirm the city's results and determine historical trends (Jarvis, 2014).

Due to these disagreements, fewer private well owners allowed their wells to be tested by the city in 2010. Private well owners also started conducting their own nitrate studies of the CAPA. In 2011, the group CAP Network conducted quarterly and subsequently annual water sampling from private wells in the CAPA. Other CAP Network projects included documenting nitrate concentrations in a rural well that had been replaced with a new sealed well that showed a reduction in nitrate concentrations (Starkey, 2017).

Both private well owners in the CAPA and Albany County officials had positive views of the CAP Network projects. The CAP Network is the only Groundwater Guardian member in Wyoming. The CAP Network well sampling project was endorsed by the Albany County Board of Commissioners and the Albany County Planning and Zoning Commission. CAP Network information was part of the public record, disseminated in a newsletter provided to CAP Network members, and presented at meetings and educational events.

In the view of private well owners, the people from the CAP Network represented private well owners and were generally trustworthy (known for being "straight shooters"). Private well owners viewed the CAP Network as friends and neighbors they trusted, and the CAP Network expert was viewed as an honest broker. The private well owners also felt greater control and ownership of the CAP Network project because they identified with the CAP Network expert who collected samples, sampling was conducted at an accredited lab, and private well owners paid for sampling and testing (CAP Network, 2011).

Some private well owners were concerned about how information from their well would be used, since there were concerns that the data would be used to regulate or harass well owners. Private well owners felt that the City of Laramie had a conflict of interest in their 2009/2010 City of Laramie well sampling because the city was also the government that could place regulations on private well owners. Private well owners did not have representation in city government.

On the other hand, the experts (who were residents of the City of Laramie) and city officials interviewed had negative views of the CAP Network projects. The experts and city officials interviewed felt that the political stance of the CAP Network was a conflict of interest.

The experts (who were residents of Laramie) interviewed mistrusted the CAP Network due to the long history of conflict (Appendix B). At the time, experts (who were residents of Laramie) felt that they placed their work online for anyone to view and associated this with transparency, good science practice, and peer review. Because data from the CAP Network Well Sampling Program was not publicly available online (it cannot be found on www.google.com), experts (who were residents of Laramie) did not make the same associations with the CAP Network program. City residents held a social stigma against the CAP Network since it did not have an online presence, which was popular at the time.

The city residents interviewed felt that they had little time to prepare questions or voice concerns about data from the CAP Network well sampling program, since information was not as widespread. These views were similar to those expressed about the Albany County Septic System Impact Analysis (Appendix C).

Table C3. Views of the CAP Network Well Sampling based on Interviews.

<table>
<tr><th>Interviewed Private Well Owners (includes Experts)</th><th>Interviewed City of Laramie Residents (includes Experts).</th></tr>
<tr><td>The CAP Network well sampling had credibility because:
Private well owners viewed the program as run by friends and neighbors they trusted, and the CAP Network expert was viewed as an honest broker.
Private well owners trusted the CAP Network expert to protect data. Private well owners were concerned that data would be used to harass well owners, or that the city would use the data to regulate or force well owners to make expensive renovations.
The program directly addressed private well owner concerns about poorly constructed and maintained wells (Starkey, 2017).
The project was endorsed by the Albany County Board of Commissioners and the Albany County Planning and Zoning Commission.
CAP Network information was part of the public record, disseminated in a newsletter provided to CAP Network members, and presented at meetings and educational events.</td><td>The CAP Network well sampling project was less credible because:
City residents did not trust the CAP Network because it was often the political opponent of city residents and experts over Casper Aquifer protection issues and the CAP Network expert was viewed as an issue advocate.
City residents viewed the CAP Network well sampling program as having less review than scientific data from governments, consultants, or academics.
City residents attached a social stigma to the CAP Network well sampling program data because it was not accessible online (though it was available through other means; see other side of Table C3).
Science conducted by government or by consultants for governments was often accessible online.
The measure of accessibility was whether scientific data could be directly accessed by a www.google.com search and was not behind a paywall.</td></tr>
</table>

D3.2.1 Jack and Jill Went Up the Hill to Fetch a Pail of… Nitrates!!!

The same conflicts over NOWTS in Laramie that motivated the CAP Network to start its well sampling program also motivated a student (who lived in a residence east of Laramie that has a private well) to study nitrate for his science fair project. The science fair project won a Junior Division Sweepstakes Award of Exceptional Merit from the 2011 State Science Fair (University of Wyoming, 2011). The student saw a data gap in the City of Laramie 2009/2010 water monitoring program, since the city did not test for background groundwater nitrate concentrations that were not impacted by septic systems (Rovani, 2012).

The student conducted two science fair projects. The first project, in 2011, sampled for nitrate from wells and springs that were up hydraulic gradient and were miles from septic systems. The second project, in 2012, examined the contribution of nitrogen-fixing plants to background concentrations of nitrate.

For the second project, in 2012, water samples were collected from Klein Springs and soil samples were collected from cryptogamic crusts that formed on the surface of the soil and from soils near mountain mahogany. The soils were leached with nitrate-free water over 49 days, based on precipitation for the area. Leachate from samples with cryptogamic crusts had the highest nitrate concentration, with a maximum concentration of 150 mg/L, while leachate from the organic materials from the ground surface near mountain mahogany and the blank had no nitrate detected. Spring waters were found to have approximately 2 mg/L of nitrate. The conclusion from the projects was that there were naturally occurring nitrate background concentrations.

In interviews, the science fair project was mentioned by private well owners more than by City of Laramie residents. Private well owners in the CAPA area had positive views of the science fair project, since the project directly studied naturally occurring nitrate, a topic that was of direct interest to private well owners.

Some of the stakeholders interviewed felt ownership of the science fair project because it was a high quality project conducted by a minor from the neighborhood with support from residents. Some local experts interviewed saw the work conducted by the student as a potential Master's thesis topic. To some stakeholders, the science fair project was an example of how stakeholders can contribute to information about NOWTS issues.

The science fair project was mentioned less by residents of the City of Laramie. The city residents interviewed lumped the science fair project with other resident science projects conducted by private well owners on the CAPA, including the CAP Network well testing. City residents shared many of the same negative views of the quality of CAP Network well testing with this science fair project.

The interviewed city residents' interpretation of the science fair project was that while the project showed background nitrate, it did not disprove that nitrate could come from septic systems. Nitrate concentrations in the subdivisions were still a concern, because nitrate concentrations were over the nitrate limits for public drinking water in some wells in the City of Laramie's 2009 sampling.

Table C4. Views of the Student Science Fair Project based on Interviews.

Interviewed Private Well Owners (includes Experts)	Interviewed City of Laramie Residents (includes Experts)
Interviewed private well owners had positive views of the science fair project because: • The project directly studied naturally occurring nitrate, a topic that was of direct interest to private well owners. • Private well owners were proud that a minor from their neighborhood completed a high quality science project. • The project showed that aquifer science was not the exclusive domain of experts.	The science fair project was mentioned less by interviewed stakeholders who were city residents because: • The science fair project was lumped with the CAP Network Groundwater Sampling Program. • While the science fair project showed background nitrate, it did not disprove that nitrate could come from septic systems.

D4. Discussion

D4.1 Why was Resident Science Created?

These case studies reveal many factors that led stakeholders to conduct resident science in La Pine and Laramie.

All the resident science case studies in La Pine and Laramie were created to build upon or verify the work of projects conducted previously by experts and consultants affiliated with governments. Stakeholders (and experts) had a level of distrust of government experts (who were viewed as issue advocates) because government expert views conflicted with local political views, values, interests, and stakeholder knowledge. Both La Pine and Laramie have a decades-long history of mistrust between experts and stakeholders that promoted the development of resident science projects as a response to government studies viewed by residents as unfair or inaccurate (Huddle, 2012; Jarvis, 2014).

In all of the case studies, there were data gaps or stakeholder concerns about the science that were not sufficiently addressed by experts. Based on reports and communications with government experts, they felt that these data gaps had already been sufficiently filled, based on their expert knowledge. They also asserted that the studies followed standard practices in the field and were created by standard practices used by experts. Experts also pointed out that they were limited by resource or political constraints (Appendix C).

Because the science of NOWTS is complex, what may be perceived as a data gap by one group may not be perceived as such by another group. One of the reasons data gaps existed was that there was a misconnection between experts and stakeholders. Experts have been academically trained to address environmental issues, while many stakeholders gain a different understanding from researching on their own, communicating with community members, and life experience.

There were also enough resources to conduct resident science. Resources include financial resources, education, active community members who support the projects, access to equipment or data, and access to experts. These resident science projects were conducted by residents who were experts and had the knowledge to find data gaps in available information. Resident scientists were also able to communicate with other resident experts—professors, scientists, hydrogeologists, and engineers—some of whom were also well owners in Laramie, or residents with graduate degrees and work experience in La Pine.

Resident science has a different set of limitation to science conducted by government experts, consultants, and academics (GAC experts). Specifically, resident science can test in locations and use methods and practices that could not be used by GAC experts.

D4.2 Impacts of Resident Science

Resident science continues to have a direct impact on politics in La Pine and Laramie. It continues to be used by residents and elected officials to successfully argue for or against regulations and policies (Bendtsen, 2020). Resident science also shaped the perspectives and attitudes of stakeholders in La Pine and Laramie.

Resident science was viewed as highly credible by some stakeholders. Residents of La Pine and private well owners near Laramie trusted resident science because they knew and trusted the community members and experts who had conducted the research.

La Pine and CAPA residents felt some degree of ownership of resident science projects because some of the residents directly participated in some part of the project, the residents shared an identity (as community members) with the residents conducting the research, and resident science directly addressed stakeholder questions and concerns, while expert studies did not.

Many La Pine and CAPA residents felt empowered or more knowledgeable of NOWTS issues after being involved or near resident science. The more knowledgeable residents were more confident and used resident science as a tool when engaging in political discourse (Jarvis, 2014; Miller, 2019).

Resident science supported divergent lines of thought on NOWTS issues. These divergent lines of thinking made it more difficult to come to a consensus on issues (Kaner et al., 2001). For example, resident science was often used by residents to contest the findings of GAC expert studies, creating a situation in which there were "dueling experts." This forced many stakeholders into a situation in which they had to decide which experts to trust.

GAC experts and regulators had mixed views of resident science. In La Pine, regulators viewed resident science as a review of expert work that corroborated expert findings, though resident science was used to contest expert findings. In Laramie, experts had negative views of resident science because resident science was used to contest expert findings. Some stakeholders were against resident science because it was conducted outside of traditional science circles (academia, government, consulting, etc.).

Table C5. Stakeholder Views of Resident Science

For Resident Science	Against Resident Science
• Resident science was created by stakeholders and experts trusted by stakeholders to conduct science. • Resident science correlated with local stakeholder knowledge and experience. • Resident science directly addressed stakeholder questions and concerns. • Stakeholders felt ownership or were proud of resident science.	• Resident science was created by people stakeholders mistrusted or who were political opponents. • Resident scientists were viewed as issue advocates instead of as honest brokers. • Stakeholders mistrusted methods, results, or data handling practices.

D5. Conclusion

Resident science is not unique to environmental conflict, but it is often not widely accepted by stakeholders or has little policy impact (Kurki, 2016). In communications with stakeholders in La Pine and Laramie, resident science was taken seriously enough by stakeholders to significantly impact politics. Though resident science impacted politics in La Pine and Laramie, there is varied stakeholder acceptance of resident science. Some stakeholders trusted resident science because it was created by experts who they trusted, it correlated with local knowledge, and it directly addressed their concerns. Resident science was mistrusted because it was created by the stakeholders' political opponents or by people they mistrusted, and because they mistrusted resident science methods or results.

Three case studies were examined as part of this study: (1) *Groundwater Protection and the La Pine Basin* (Huddle, 2012), (2) CAP Network Groundwater Sampling Program (Starkey, 2017), (3) Jack and Jill Went Up the Hill to Fetch a Pail of… Nitrates!!! (Rovani, 2012).

Based on resident science case studies, four factors led to the creation of resident science in La Pine and Laramie: (1) stakeholders mistrusted studies conducted by experts and regulators; (2) stakeholders had the knowledge to find data gaps; (3) stakeholders had sufficient funding, expertise, and equipment to conduct their own research; (4) resident science built upon, disputed, or verified the work of contentious government studies.

One recommendation is to leverage resident science in NOWTS conflict through the use of joint fact-finding. Resident science had multiple positive outcomes because it empowered stakeholders and supported alternative views of NOWTS. As part of the joint fact-finding, resident scientists could work together with opposing stakeholders (or experts) to address the outcomes of resident science that escalate conflicts. An example of a possible compromise for the CAP Network Groundwater Sampling Program would be for the CAP Network and opposing stakeholders to develop data use practices that address private well owner concerns about data being used against them while also addressing opposing stakeholder concerns about resident science taking place outside of traditional science circles (academia, government, consultants, etc.). Potential strategies might involve using confidentiality agreements to give opposing experts access to data while protecting the confidentiality of the data, or setting community rules for the use of all science in political settings.

Some groups in La Pine and Laramie have made steps toward working together in the past but stopped when conflicts occurred due to misunderstandings. While someone could be brought in to mediate these issues, it may be easier and less resource intensive to create rules for when conflicts occur. The rules could be simple. An example could be, "If there is conflict based on email or other forms of written communication, then the groups will meet to talk about the conflict in person." Conflicts over data are an opportunity to employ joint fact-finding.

D6. References

Bendtsen, D., 2020, Commissioners vote 2-1 on contentious zoning change: Laramie Boomerang 7 January, Laramie Wyoming. https://www.laramieboomerang.com/news/local_news/commissioners-vote-2-1-on-contentious-zoning-change/article_495f03ad-c6f2-5296-8a99-075ddcfd541f.html

Bryer, T.A., 2009, Explaining Responsiveness in Collaboration: Administrator and Citizen Role Perceptions: Public Administration Review, p. 271–283.

Burch, S., Sheppard, S.R.J., Shaw, A., and Flanders, D., 2010, Planning for climate change in a flood-prone community: municipal barriers to policy action and the use of visualizations as decision-support tools: Planning for climate change in a flood-prone community: Journal of Flood Risk Management, v. 3, p. 126–139, doi:10.1111/j.1753-318X.2010.01062.x.

CAP Network, 2011, CAP Network News Letter February 2011:

City of Laramie, 2010, Report on Summer/Fall 2009 Nitrate-Nitrogen Monitoring in the Casper Aquifer Protection Area: City of Laramie.

Gehle, K., 2013, ATSDR Case Studies in Environmental Medicine: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry WB2342, 135 p.

Groundwater Foundation, 2017, 2017 Groundwater Guardian Profiles: Groundwater Foundation, 70 p.

Haderlie, C., 2010, Nitrate Levels in well water unsafe: Laramie Boomerang 14 July, Laramie, Wyoming, https://www.laramieboomerang.com/news/nitrate-levels-in-well-water-unsafe/article_67baf722-bac4-56e7-9e87-85db0bc5aacd.html

Hammers, S., 2012, Nitrate levels show no pattern: The Bulletin 5 February, Bend, Oregon, p. 2.

Hofman, J., 2007, Septic Smiles: The Bulletin 7 January, Bend, Oregon, https://www.bendbulletin.com/opinion/septic-smiles/article_13f1a414-6d37-5ec6-8af7-566611781b84.html.

Huddle, J., 2012, Ground-water Protection and the La Pine Basin:

Jarvis, W.T., 2014, Contesting Hidden Waters: Conflict resolution for groundwater and aquifers: Routledge, Earthscan Water, 192 p.

Kaner, S., Lind, L., Toldi, C., Fisk, S., Berger, D., and Doyle, M., 2001, Facilitator's Guide to Participatory Decision-Making: Gabriola Island, BC, New Society Publishers, 255 p.

Kurki, V., 2016, Negotiating Groundwater Governance: Lessons from Contentious Aquifer Recharge Projects: Tampere University of Technology, 169 p., https://tutcris.tut.fi/portal/files/6149146/Kurki_1387.pdf.

Miller, C., 2019, Miller: Hinckley's aquifer arguments lack merit: Laramie Boomerang 8 December, Laramie, Wyoming, https://www.laramieboomerang.com/opinion/guest_column/miller-hinckley-s-aquifer-arguments-lack-merit/article_90e4449b-68a0-5655-ba4e-4a5d9191dfb2.html (accessed December 2019).

Morgan, D.S., Hinkle, S.R., and Weick, R.J., 2007, Evaluation of Approaches for Managin Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey, Oregon Department of Environmental Quality, Descuntes County Scientific Investigations Report 2007–5237, 66 p.

Nigg, E., and Baggett, R., 2013, South Deschutes/North Klamath Groundwater Protection: Report and Recommendations: Oregon Department of Environmental Quality, 32 p.

Nyerges, T., Jankowski, P., Tuthill, D., and Ramsey, K., 2006, Collaborative Water Resource Decision Support: Results of a Field Experiment: Annals of the Association of American Geographers, v. 96, p. 699–725, doi:10.1111/j.1467-8306.2006.00512.x.

Phillips, T., Bonney, R., and Shirk, J.L., 2012, Chapter 5: What Is Our Impact?: Toward a Unified Framework for Evaluating Outcomes of Citizen Science, *in* Citizen Science: Public Participation in Environmental Research, Cornell University Press, p. 82–96.

Ramsayer, K., 2006, Residents quiz geologists on La Pine water: The Bulletin 21 December, Bend, Oregon, p. 2.

Rich, B., 2005, Final Report: La Pine National Demonstration Project 1999-2005: Deschutes County, ODEQ, USGS, 329 p.

Rovani, S., 2012, Jack and Jill Went Up the Hill to Fetch a Pail of... Nitrates!

Schroeder, P.E., Brandhuber, P., and Thompson, K., 2013, East Laramie Waste Water Feasibility Study: City of Laramie, WWC Engineering, http://albanycountycleanwateradvocates.org/wp-content/uploads/2017/11/item-13-report-link.pdf (accessed February 2019).

Starkey, K., 2008, Give credit where credit is due: Laramie Boomerang 18 September, Laramie, Wyoming.

Starkey, R., 2017, Overview of the Casper Aquifer Protection Network Groundwater Sampling Program: presented to the Albany County Board of County Commissioners and to the Albany County Planning and Zoning Commission.

Stollar, C., 2006, La Pine water plan raises doubts: The Bulletin 10 April, Bend, Oregon, p. 4.

University of Wyoming, 2011, Laramie, Greybull Students Top State Science Fair Winners: University of Wyoming, http://www.uwyo.edu/uw/news/2011/03/laramie,-greybull-students-top-state-science-fair-winners.html (accessed June 2020).

Wittman Hydro Planning Associates (WHPA), 2008, Casper Aquifer Protection Plan: City of Laramie, Wittman Hydro Planning Associates, 334 p.

Appendix E:

Sole Source Aquifer Petition for the La Pine Subbasin Aquifer

The following is the Sole Source Aquifer Petition, which had specific formatting requirements, so screen shots were taken to preserve formatting and page numbering. For original documents contact:

David Demaree

Telephone: 650-302-7688 (please text)

Email: demareda@oregonstate.edu, or dhdemaree@gmail.com

Sole Source Aquifer Petition Guidance

(Do not submit this page with Document)

1. Agree upon the following areas. Definitions and guidance on areas can be found on the EPA website. https://nepis.epa.gov/Exe/ZyNET.exe/2000Y00Z.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1986+Thru+1990&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C86thru90%5CTxt%5C00000014%5C2000Y00Z.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL –
   - Aquifer
   - Aquifer Service Area
   - Designated Area
   - Project Review Area
   - Recharge Area
   - Stream Flow Source Area

2. Edit Document, and maps to reflect changes Step 1.

3. Fill out red sections which have to be filled out specifically by the petitioner, and make final edits to the document.

4. Add current date to footer.

5. Fill out page numbers on the Table of Contents and Appendix E: Completeness Determination Checklist

6. Call - 1-800-424-4EPA (1-800-424-4372) for more information before submitting

7. 4 copies of the Sole Source Aquifer Petition should be submitted to the Region 10 EPA Office.

Office of Groundwater
EPA Region 10
1200 6th Ave.
Seattle, WA 98101

Sole Source Aquifer Designation Petition

for the

La Pine Subbasin Aquifer

(Date Petition is filled out)

Prepared by:
(Petitioner)

With Technical Assistance from:
David Demaree, Oregon State University, Corvallis OR.

EPA APPENDIX E

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
I. Petitioner Identifying Information		
All items on the suggested petitioner identifying format should be completed (see Exhibit 3-6). Attach a complete copy of the format to this checklist.	Page 1	
II. Narrative		
A Reasonable response for each of the following topics should be included. Each Topic should be described in approximately one paragraph:		
• General Location of the Aquifer	Page 3	
• Ground-water dependency in the area and on the particular aquifer for which designation is requested.	Page 4	
• Availability of other public water supplies	Page 5	
• Reasons for interest in SSA designation	Page 6	
• Why the Aquifer is vulnerable to Contamination	Page 7	
• Quality of the water from the aquifer	Page 8	
• Relationship of the petitioner to the purveyor(s) of the water supply	Page 8	

EPA APPENDIX E (3)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
III. (continued)		
C. Current Sources of Drinking Water		
1. Information similar to that requested on the "Current Drinking Water Sources Matrix	Page 10	
2. A brief narrative description of each current source, with method(s) used for calculating the percentages used in the matrix	Page 10	
3. Explanation of seasonal variations	Page 11	
4. Explanation of actual use versus potential capacity	Page 11	
5. Explanation of why the source is not currently to its full capacity	Page 12	

EPA APPENDIX E (2)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
III. Sole or Principal Determination		
Information should be sufficient to determine whether the aquifer is the sole or principal drinking water source for the aquifer service area.		
A. Aquifer service area		
1. Description of the aquifer service area	Page 9	
2. Map delineating the boundaries of the aquifer service area	Plate 1	
B. Population		
1. Total population with in the aquifer service area	Page 10	
2. Population served by the aquifer	Page 10	

EPA APPENDIX E (3)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
III. (continued)		
C. Current Sources of Drinking Water		
1. Information similar to that requested on the "Current Drinking Water Sources Matrix	Page 10	
2. A brief narrative description of each current source, with method(s) used for calculating the percentages used in the matrix	Page 10	
3. Explanation of seasonal variations	Page 11	
4. Explanation of actual use versus potential capacity	Page 11	
5. Explanation of why the source is not currently to its full capacity	Page 12	

EPA APPENDIX E (4)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
III. (continued)		
D. Alternative Source of Drinking Water		
1. Information Similar to that requested on the first version of the "Alternative Drinking Water Sources" matrix	Page 13	
2. Information similar to that requested on the second version of the "Alternative to Drinking Water Sources" matrix	Page 13	

EPA APPENDIX E (5)

III. D. (continued) Alternative Source of Drinking Water

Requested Item	La Pine Subbasin Aquifer		Surface Water	
	Inc.	Not Inc.	Inc.	Not Inc.
3. Narrative Description	X		X	
4. Why source not currently in use	X		X	
5. Legal or institutional constraints	X		X	
6. How estimated daily supply was calculated	X		X	
7. What is necessary to transfer to this	X		X	
8. Estimated cost to provide water of comparable quality	X		X	
9. Determination of economic feasibility	X		X	

EPA APPENDIX E (6)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
III. Hydrogeological Data		
A. Aquifer and its location		
1. Narrative description of the locale, including topography, climate, geology, groundwater use and occurrence.	Page 14	
2. Delineation (plane view) of aquifer's boundaries on USGS 7.5 or 15 min quad topographic maps; delineation of very large aquifers area greater than 1,000 mi^2) on 1:100,000 scale maps	Plate 1	
3. Detailed (as necessary) descriptions and diagrams of aquifers: hydrogeology including:		

EPA APPENDIX E (7)

COMPLETENESS DETERMINATION CHECKLIST

IV.A (continued)

	INCLUDED	NOT INCLUDED
• Delineation of the aquifer and non-aquifer units	Page 17	
• Longitudinal and transverse geologic cross sections depicting the aquifer	Plate 2-3	
• Data or estimates concerning aquifer characteristics such as porosity, hydraulic conductivity, direction of ground-water flow, well yields	Page 11, 18	
4. Description of discharge or ground-water withdrawal from the aquifer for example:	Page 18	

- Wells (drinking, irrigation, industrial)
- Springs
- Stream baseflow
- Maps showing water table contours or potentiometric surfaces, springs and surface water pathways.

EPA APPENDIX E (8)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
IV. (continued)		
B. Recharge Areas(s)		
1. Delineation of recharge area(s) on topographic maps	Plate 1	
2. A description of methods used to determine recharge area(s), for example:	Page 19	
• Assessment of topographic, geologic or hydrogeologic maps		
• Review and assessment of regional and subregional ground-water flow system(s) data		
• Data obtained from field studies based on isotopic dating techniques observation well networks, tracer tests, etc.		
• Numerical simulation, i.e., regional flow modeling		

EPA APPENDIX E (9)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
IV.B (continued)		
3. Description and location of natural and man-induced aquifer recharge such as precipitation, snow melt, unlined surface impoundments, irrigation, injection of fluids and injection wells.	Page 19	
C. Stream flow source Areas		
Note: If the streamflow source area is not included in the project review area, there should be a statement as to why it has not been included.	Plate 1, Page 20	
If the streamflow source area has been included in the project review area, the following information is requested:		
1. Delineation of the streamflow source area on detailed topographic maps including location of losing streams, if such streamflow demonstrably contributes to the aquifer through these areas	Page 20	
2. Explanation of methods used in determining stream flow contributions.	Page 20	
3. Streamflow characteristics including delineation of gaining and losing portions of streams	Page 20	

EPA APPENDIX E (10)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
III. Hydrogeological Data		
D. Designated Area		
Delineation of the proposed designated area on a topographic map	Plate 1	
E. Project Review Area		
Delineation of the proposed project review area on a topographic map	Plate 1	
F. Reference Map		
An 8.5 x 11 inch or 8.5 x 14 inch reproducible reference map indicating 1. The sole source aquifer area 2. County/parish boundaries 3. Major streams and lakes 4. Cities and towns 5. Latitude and longitude of a reference point with in of the petitioned aquifer service area 6. Other information that contributes to a clear understanding on the location of the area and its relation to other major political and physical features 7. An inset map show the aquifer location with the state	Page 29	
G. (At the option of the Petitioner) Minimum set of Data Elements for Public and/or Private Water Wells and Springs producing water from the petitioned aquifer for drinking water that is supplied within the aquifer service area	N/A	

EPA APPENDIX E (10)

COMPLETENESS DETERMINATION CHECKLIST

	INCLUDED	NOT INCLUDED
IV. (continued)		
General Description		
1. Data Sources	N/A	
Geographic Descriptors		
2. Latitude 3. Longitude 4. Method used to determine latitude and longitude 5. Description of Entity 6. Accuracy of Latitude and Longitude Measurement 7. Altitude 8. Method Used to determine Altitude 9. State FIPS Code 10. County FIPS Code	N/A	
Well Descriptors		
11. Well Identifier 12. Well Used 13. Type of Log 14. Depth of Well at Completion 15. Screened/Open Interval	N/A	
Sample Descriptors		
16. Sample Identifier 17. Depth to water 18. Constituent or Parameter Measured 19. Concentration/Value 20. Analytical Results Qualifier 21. Quality Assurance Indicator	N/A	

TABLE OF CONTENTS

Appendices

Table No.

LIST OF PLATES

(Plates Follow Petition Text)

Plate No.

SECTION I

PETITIONER IDENTIFYING INFORMATION

Aquifer:	*Name:*	La Pine Subbasin Aquifer
	Location:	Townships 20 – 22 South, Ranges 9-11 East near the City of La Pine, Deschutes County, Oregon
Petitioner:	*Name:*	(Petitioning Organization)
	Address	(Petitioning Organization)
	Phone No.:	(Petitioning Organization)
	Email:	(Petitioning Organization)
Responsible Person:	*Name:*	(Petitioning Organization)
Contact:	*Name:*	David Demaree (Oregon State Graduate Student) 104 Wilkinson Hall Corvallis, Oregon 97331
	Phone No.:	(650) 302 - 7688
	Email:	demareda@oregonstate.edu

SECTION II

INTRODUCTION (NARRITIVE)

Definitions

City of La Pine – also referred to as La Pine. The area and people which are part of the incorporated city of La Pine, OR.

La Pine Area – also referred to as La Pine Region (Morgan et al 2007), greater La Pine Area (City of La Pine, 2017). The region which includes the City of La Pine and outlying areas.

La Pine Subbasin (Gannett, 2005) – also referred to as Little Deschutes River Subbasin (Upper Deschutes Watershed Council, 2002), Lapine Basin (Gannett, 2005) - The La Pine Subbasin is the south western portion of the Upper Deschutes Basin, between the Cascade Range and the Newberry Volcano.

La Pine Subbasin Watershed – The La Pine Subbasin Watershed is the area in which precipitation contributes to discharge at Benham Falls on the Deschutes River. This area ranges from the crest of the Cascade Range to the crest of the Newberry Volcano.

Location and Description of Project Area

The City of La Pine is located in the Upper Deschutes River Basin of central Oregon in Deschutes County. La Pine is located in a transition area between the Cascade Range, High Lava Plains, and the Basin and Range Province at an elevation of 4,235 ft. The total project review area is approximately 40 mi^2 which is dispersed over an area 18 miles long and 12 miles wide. This area was covered in Deschutes County planning Goal 11 exception hearings (2015) and covers many of the developed areas in the La Pine Area.

There were 1,653 residents in the City of La Pine in the 2010 US Census, with an estimated population of 1,777 by 2015. La Pine is a rural community with an estimated 18,000 residents in the La Pine Area (Morgan et. al 2007). Current and future growth is attributed to increased tourism in the area as well as the aesthetic landscape of the surrounding areas.

Water for the core area of the city of La Pine is provided by the La Pine Water District which maintains two wells and two reservoirs one 1.2 million gallons and the other 250,000 gallons. Most of the residents in the area outside of the city of La Pine have their own private wells. The La Pine Water District provides water to approximately 1600 people of the 18,000 people in the La Pine area, the rest of whom are on wells (Morgan et. al 2007).

Location of La Pine Aquifer System

The La Pine Aquifer System encompasses approximately 287 square miles or 183,680 acres (see Plate 1). In parts of Townships 20, 21, 22, 23, 24, 25, and 26 South and Ranges 7, 8, 9, 10 and 11 East. The La Pine Aquifer System is shaped like an irregular oval with its longest dimension being approximately 43.4 miles from southeast to northwest. The widest area is 29.4 miles from north west to south east. The boundaries were determined based on the location of quaternary sediments on a composite geologic map of Oregon (Ma et al., 2009). The aquifer is located in sand and gravel deposits in the quaternary sediments and precipitation and streams flowing through this area contribute to water into the aquifer.

Groundwater Dependency

City of La Pine. The core of the City of La Pine receive water from two public wells located near Finley Butte, which are 251 ft. and 254 ft. deep and can be pumped at 600 gallons per minute (Baird, 2016a). Many parts of the city, which include areas with residential, commercial, government buildings, and schools, are not on the public water system instead receiving water from their own individual wells.

Outlying Areas. Residential and drinking water use outside of the City of La Pine is almost entirely dependent on private domestic wells. Most residential wells are shallow and less than 50 ft. deep and withdraw water from the La Pine Subbasin Aquifer

Other Potential Public Water Supply Sources

Potential Groundwater Alternatives. No other reliable aquifer exists in the La Pine area.

Potential Surface Water Alternatives. There are multiple streams and reservoirs in the La Pine Subbasin Basin near the City of La Pine which include, Crescent Creek, Little Deschutes River, Long Prairie Slough, Paulina Creek, Deschutes River, Wickiup Reservoir, and Crane Prairie Reservoir, Crescent Lake. The water rights for these streams and reservoirs has been fully allocated.

According to the 2010 US Census the average household income in the City of La Pine was $25,848, so any costs >$155 would be prohibitive to residents. The La Pine Area is rural with a low population density, so it would be expensive to extend and maintain a public water system, especially if it brings water from outside the La Pine Subbasin without assistance.

Water Rights. The use of the rivers in the area which include Crescent Creek, Little Deschutes River, Long Prairie Slough, Paulina Creek, Fall River, and Deschutes River as a water supply alternative is dependent upon the priority of the water rights issues associated with such use. The average discharge from the La Pine Subbasin at Benham Falls is 1106 cfs. The Tumalo Irrigation District, east of Bend, use to own Crescent Lake Reservoir has a water right from 1905 for 9.5 cfs. Arnold Irrigation District, south of Bend, has a water right from 1905 for 150 cfs. The North Unit Irrigation which is north of Bend and owns Wickiup Reservoir has a water right from 1913 for 1104 cfs (Campbell 2015). The Central Oregon Irrigation District also has a water right to water from the Crane Prairie Reservoir (USBR, 2017). The city of Bend has a water right in the Deschutes River which drains from the La Pine Subbasin and along with instream water rights for fish and the environment.

Within the designated area there are 11 surface water rights for domestic and drinking water use. These water rights are for Paulina Creek and the Fall River with rights to individually withdrawal ≤ 0.015 cfs, or 0.085 cfs of total withdrawals, and priority dates ranging from 1899 to 1950. There are other surface water rights within the designated area but the primary uses are for fisheries, and irrigation and not for drinking water.

In Oregon water rights based on prior appropriation, a legal doctrine where those with the oldest water right have first access to water, if residents of the La Pine area were given a surface water right they would not be able to make use of the right for most of the year because surface water rights have been fully allocated based on average flows. Due to the full allocation of water rights and the arduous nature of obtaining water rights in the State of Oregon, surface water sources are not viewed as plausible alternative to supply the La Pine Area.

The city of La Pine has a water right to 1000 cfs of groundwater with a priority date of 2010 (Baird, 2016a). The residents of the greater La Pine area use ground water since not permit is needed for domestic wells < 15,000 gallons per day, stock watering, school grounds watering, and commercial and industrial < 5,000 gallons per day (Cole 2006).

Reasons for Interest in the Sole Source Aquifer Designation

The City of La Pine and outlying areas depend on groundwater as their main source of drinking water. Nitrate contamination was first found in the aquifer in 1979 and the highest concentration of nitrate was found to be 26 mg/L which is over the 10 mg/L nitrate MCL set by the US EPA (Morgan 2007). A series of studies and County Planning rules have been passed in order to protect the aquifer.

(Petitioning Organization) is applying for Sole Source Aquifer designation in order to obtain official acknowledgement of the fact that the La Pine Subbasin Aquifer is the only drinking water source utilized by the community and to raise community awareness about the importance of keeping the aquifer free from contamination. The City of La Pine and outlying areas are surrounded by public lands including the Deschutes National Forest and are managed by the Bureau of Land Management or Deschutes County.

(Petitioning Organization) request the Sole Source Aquifer Designation for the La Pine Subbasin Aquifer as part of a water supply management approach to protect drinking water supply. (Petitioning Organization) hopes to obtain this status for the aquifer so that the EPA will review federally-funded projects located in the La Pine area to insure that projects are conducted in a manner which will not negatively impact the aquifer system.

Vulnerability of the Aquifer to Contamination

Because the La Pine Aquifer System is a shallow unconfined aquifer the aquifer is vulnerable to human activities, including the spilling of contaminants on the ground, fertilizer usage, increased housing development, septic tank and wastewater treatment effluent disposal, and contamination from a variety of activities in recharge areas. The recharge area includes, privately owned land mainly residential, land managed by the U.S. Forest Services and Bureau of Land Management, and land managed by Deschutes County. The potential threats to the aquifer are mainly related to forest harvesting, agriculture, transportation, and developments which require septic tanks, and fertilizers.

Quality of Water from the La Pine Aquifer

The quality of the water developed from the La Pine Aquifer system is good. According to the 2015 City of La Pine Water Quality Report the concentration of nitrate was 0.07 ppm, copper was 37 ppb, lead 2.0 ppb, which was below action levels or MCL for all contaminants. At the time of the water quality report both of the city wells had been contaminated with Coliform bacteria and there was a public announcement to boil water. Nitrates have been found over the MCL for nitrates water from wells since the 1979 when the first well with nitrates over the EPA MCL of 10 mg/L was found.

Relationship between the Petitioner and Water Supply Purveyors

To be filled out by organization applying for the designation.

SECTION III

SOLE OR PRINCIPAL DETERMINATION

Aquifer Service Area

The aquifer service area, defined as the area above the aquifer and including the area where the entire population served by the aquifer lives is located entirely within the La Pine Subbasin Aquifer Area depicted Plate 1. For this petition areas covered by the La Pine Subbasin Aquifer are the same as the aquifer service area, designated area, and recharge area. The aquifer service area can be described as:

- Parts of Townships 20 – 26 South, Ranges 7-11 East, OR
- The designated area includes the city of La Pine and many of the surrounding subdivisions or areas open for development. The petition area are the areas which were part of the 2015 goal 11 exception area. The aquifer is in the heterogeneous volcanic and quaternary sediments which have filled the graben between the Cascade Range and Newberry Volcano.

Plate 1 depicts the boundaries of the service area on a 1:100,000 scale USGS topographic map.

Population

Total Population within the Aquifer Service Area. In the 2010 US census the City of La Pine had 1,653 residents with an estimated population of 1,777 by 2015. La Pine is a rural community with an estimated 18,000 residents in the La Pine Subbasin (Morgan et. al 2007)

Population Served by the Aquifer. It is estimated that 18,000 people are served by the aquifer who live on over 9300 privately owned lots that range in area from 0.5 acres to 10 acres (Aha 2015).

Current Sources of Drinking Water

Sources Matrix. The Current Drinking Water Sources Matrix is presented in Table 1. The La Pine Subbasin Aquifer is estimated to provide 99% of drinking water to the population of the Aquifer Service Area. The La Pine Subbasin Aquifer is the main source of water for the City of La Pine, and is one of the main sources of water for the population in the aquifer service area.

Description of Current Water Sources. The majority of La Pine Area residents receive their water from private domestic wells which are located on their own property. Many public buildings, and businesses also receive their water from domestic wells. Many parts of the core of the City of La Pine receives water from the La Pine Water District which receives water from two public wells located near Finley Butte, which are 251 ft. and 254 ft. deep and pump at a rate of 600 gallons/minute (gpm) (Baird, 2016a).

Seasonal Variation. The average daily demand during 2015 for the City of La Pine was 198 gpm, and the peak demand was 477 gpm (Baird 2016a). The peak water demands occur during the summer and are associated with, high temperatures, little precipitation, irrigation of lawns and gardens, as well as other beneficial uses.

Actual Use Versus Potential Capacity. Based on studies by the USGS which are reported in (Morgan et al, 2007); the porosity of the aquifer is 0.30 the depth of the aquifer ranges from 10 – 100 ft. The geological formation the La Pine Subbasin Aquifer is in Quaternary sediments the surface area of the sediments is approximately 387 square miles which is based on (Ma et al. 2009). Assuming the average thickness of the aquifer is 50 ft. there is 1.21×10^{12} gallons of water in the aquifer. Assuming that average water demand for the City of La Pine 198 gpm for 982 residents (Baird, 2016a) is consistent across all La Pine Subbasin residents, 18000 people (Morgan, 2007). Then the average water demand is 1.91×10^{9} gallons/year or 3500 gpm. Given current rates of withdrawal the La Pine Subbasin Aquifer will adequately supply water for the residents of the La Pine Area for the near future, and may supply additional residents assuming the aquifer is adequately protected.

TABLE 1

CURRENT DRINKING WATER SOURCES

FOR AQUIFER SERVICE AREA

Source	Public Water Supply (Community and Non-Community)	Private and Other	Total
Petitioned Aquifer	9%	90%	99%
Other Aquifers	--	--	--
Surface Water	--	1%	1%
Transport from the Outside	--	--	--
Total	9%	91%	100%

Reasons for the Amount of Use. The La Pine Area residents do not use the La Pine Subbasin Aquifer System to its full capacity because the aquifer is capable of producing far more water than residents can currently use. The city of La Pine has an average water use of 325 gpm or 0.72 cfs and has a water right for 1000 gpm. If the average water use by the city of La Pine is scaled up to the population of the La Pine Subbasin then the Subbasin Water use is estimated to be 3502 gpm or 7.8 cfs. Surface water rights for domestic water use only account for 0.085 cfs or potential drinking water. Considering predicted growth trends, the capacity of the Caster Aquifer System is significantly greater than demands that may be put on it in the near future.

Alternate Sources of Drinking Water

As discussed in detail in Section II of this petition, there are no viable sources for a community water supply other than the La Pine Subbasin Aquifer system for the La Pine Area. Development of surface water is unfeasible due to difficulties in obtaining water rights and the cost of building new infrastructure.

Table 2

Alternate Sources of Drinking Water

(A) Petitioned Aquifer Supply 3502 gpm (5,042,880 gpd)

SOURCE	ESTIMATED DAILY SUPPLY
(B) Other Groundwater Sources	0
(C) Surface Water	0
	(E) Total: 0 gpm (0 gpd)

SECTION IV

HYDROGEOLOGICAL DATA

Aquifer and its Location

Based on the geologic surveying the designated area is within a graben which is filled with quaternary fluvial sediment and bounded by Pleistocene and Pliocene, basalt and andesite. The fluvial sediment is heterogeneous and is composed of a mix of coarse fluvial sand, silt, clay, and discontinuous deposits of cinder, pumice and ash fall (Morgan et al 2007, Ma et al. 2009). The aquifer is unconfined and most of the water for the aquifer is produced from areas with course sand and gravel, while silt and clay deposits are less permeable, and less likely to produce water.

Topography. The lowest point in the La Pine Subbasin is Benham falls (4,153 ft.) at the north part of the basin, and the highest point is the South Sister (10,358 ft.) which is in the north western part of the aquifer. The Cascade Mountains are to the west and Newberry Volcano (Paulina Peak) to the east. The elevation of the subbasin increases to the south. The subbasin also contains many volcanic buttes and lakes in the western part of the subbasin.

Climate. La Pine is in a transition climate zone between the Cascade Range which can have >70 inches of precipitation and the High Desert which can have less than 10 inches or rain per year. The La Pine

Area has between 16 – 24 inches of precipitation per year (Morgan et al, 2007), and the temperatures can range from the high 90°F's to -20°F's with a mean temperature of 40-44°F (Gannett, 2005).

Geology of the La Pine Subbasin

Geologic map and cross sections are included on Plate 2 and Plate 3

Structural Setting. La Pine Area lies within the La Pine Subbasin of the Upper Deschutes Basin of central Oregon. The La Pine Subbasin is located at the convergence of the Cascade Range, High Lava Plains and the Basin and Range. The subbasin is bounded on the west by the Cascade Range, and to the east by the Newberry Volcano. The subbasin is in a graben formation that has been filled with fluvial sediment from surrounding material of volcanic origin. The sides of the graben are composed of basalt and andesite (Morgan, 2007).

Local Structural Geology. Structures in the La Pine Subbasin include, the graben structure the La Pine Subbasin Aquifer is located in, New Berry Volcano and Cascade Range. The Newberry volcano is a shield volcano to the east of the graben and volcanic material is mainly basalt or rhyolite. To the west of the graben are a series of smaller volcanic buttes composed of basalt and rhyolite which compose the foothills of the Cascade Range, and further west are the Cascade Range which is a volcanic mountain range. The graben is between the Cascade Range and New Berry volcano and is estimated to be filled with 1400 ft. of sediment (Morgan 2007). The cross section on Plate 2 and Plate 3 depict the sedimentary structures located in the graben.

Hydrostratigraphy. The geologic composition of the sides of the graben the La Pine Subbasin Aquifer are part of the Cascade Range and Newberry Volcano consist of basalt, basaltic andesite and tuff (Morgan, 2007) are relatively impermeable due to metamorphism and remineralization from volcanic activity (Gannett, 2005), and are a boundary for the La Pine Subbasin Aquifer. The La Pine Subbasin Aquifer covers an area of approximately 287 square miles based on geologic formations from (Ma et al., 2009). A similar but slightly different area for the aquifer is mentioned in (Cole, 2006)

Unconsolidated sedimentary material which forms the La Pine Subbasin Aquifer consist of clay-silt, pumice-sand, sand, sand-gravel and gravel. The sedimentary material is relatively heterogeneous. Water is mainly produced from gravel and sand deposits in the aquifer area. The lower part of the aquifer and some areas closer to the surface contain clay deposits that are relatively impermeable and produce little to no water.

Above the clay-silt sediments are more permeable alluvial sediments composed of gravel and sand which are interbedded in some areas. These sediments compose the main body of the aquifer and range from 10 ft. to 100 ft. below the grounds surface (Morgan, 2007).

The surface soils of the area of the La Pine Subbasin Aquifer are often described as pumice sand (Morgan, 2007) and are classified under 4 soil types: (1) Tutni Loamy coarse sand, which is mainly in stream terraces in the southeastern part of the aquifer area, and consists of very dark grayish brown loamy coarse sand. (2) Cryaquollis instream sediments and consists of dark brown silt to silt loam. (3) Sunriver sandy loam in stream terrace and wetland sediment and consists of dark grey sandy loam. (4)

Shanahan loamy coarse sand, is mainly in the floodplains and hills and consists of dark brown to yellowish brown loamy coarse sand. These soils have high permeability, are poorly drained have a water table near the ground surface, and consist of alluvial sediment with high ash and pumice content (Gannett, 2005). Some of the sediments also contain intact diatoms which will compress under large structures (Spurr, 2017).

Groundwater Use and Occurrence. As discussed in Section II of this petition, the available information indicates that no formation other than the La Pine Subbasin Aquifer System yields sufficient quantities of water to wells to warrant economic development.

Delineation of the Aquifer (Designated Area) Boundaries. The La Pine Subbasin Aquifer System covers a large area of approximately 287 square miles. The designated area is delineated on Plate 1. The boundaries of the designated area were delineated based on geologic maps of the area (Ma et al. 2007) which were interpreted to contribute water to the La Pine Subbasin Aquifer System.

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Description of the La Pine Aquifer System. The La Pine Aquifer System consists of the saturated portions of the unconsolidated Quaternary sediments in the La Pine Subbasin. The La Pine Aquifer is bounded by basalt, andesite and tuffs to the east and west and below by lacustrine silts and clays. The cross sections shown on Plate 2 and Plate 3 depicts the hydrology of the La Pine Subbasin Aquifer and geology of other rock units.

Discharge and Groundwater Withdrawals from the Aquifer. The only known locations of groundwater withdrawal from the La Pine Aquifer System with in the area designated by this Sole Source Aquifer Petition, are from small private and public wells that pump under <5,000 gallons per day, and from municipal public wells.

Wells. Only a small portion of La Pine Area in the core of the city of La Pine is connected to municipal water. All other developed areas in the La Pine Area depend on small private domestic wells. These wells are used for residential, commercial, industrial, agricultural, and for some government buildings.

Municipal Water. Municipal water is provided to an estimated 982 residents in the city of La Pine in 2014 by the La Pine Water District. Water is withdrawn from 2 wells and there is a combined water right of 1000 gpm from each well (Baird, 2016).

Potentiometric Surface. Recharge to the aquifer occurs from precipitation into the watershed. The streams in the La Pine Area both gain and loses water to the La Pine Subbasin Aquifer but there is little net gain or loses (Morgan et al., 2007). The soil in the La Pine area is highly saturated and the water table of the La Pine Subbasin Aquifer is relatively shallow and ranges from less than 2 ft. to over 40 ft., and changes seasonally, and is shallower during the winter and deeper during the summer.

Stream Base flow. The stream base flow based on discharge measured at the Benham Falls station on the Deschutes River is approximately 500 cfs. The flow in the river is mainly controlled by releases from the reservoirs in the La Pine Subbasin. If there were no reservoirs the streams would have snow based hydrology with lowest flows in October and highest flows in early spring, and stream base flow would be much lower.

Delineation of Project Review Areas. The Project Review area is approximately 40 square miles. The designated area represents areas that have been develop or may be developed in the La Pine area and are areas where residents depend on groundwater from private and public wells. The Project Review Area is based on Goal 11 exception areas from (Russell et al., 2016), and the municipality of La Pine. Part of Oregon State Planning Goal 11 (OAR 660-015-0000(11)) disallows sewer systems outside of urban growth boundaries or unincorporated communities, the exception was to allow for sewers or other community waste water treatment options.

Recharge Area

Aquifer Recharge Sources. Recharge water enters the La Pine Aquifer System through the highly permeable unconsolidated Tutni, Cryaquollis, Sunriver and Shanahan soils which have a high ash and pumice content, as well as deeper sand and gravel deposits. The aquifer recharges from precipitation and from streams that flow in to the aquifer area. For this petition the Aquifer Area on Plate 1 is the same as the Recharge Area.

There are no injection wells in the recharge area for the La Pine Aquifer System. There are areas in the La Pine Area that are irrigated such as yards and gardens during the summer, and effluent from the waste water treatment plant is used to water hayfields. Irrigation water does reach the aquifer from watering fields and gardens (Braid 2016b). There should be no recharge of the aquifer from lined lagoons for the wastewater treatment plant or from the reservoirs (steel tanks) use for drinking water. There are multiple reservoirs in the La Pine Subbasin including Wickiup, Crescent Lake and Crane Prairie (USBR, 2016), which may provide recharge to the La Pine Subbasin Aquifer.

There is more recharge in to the La Pine Subbasin aquifer from precipitation than there is water withdrawn. Therefore groundwater tends to follow topography with streams being the low discharge point for the aquifer and the water table increases further away from streams. Ground water flows from the recharge areas at the edge of the aquifer predominantly on the Cascades side of the watershed, until it discharges into the streams in the La Pine Subbasin (Morgan et al. 2007).

Streamflow Source Area

(This section should edited by organization submitting document)

The stream flow source area have not been included as part of this petition, because there is little net gain or loss from streams which cross the aquifer area (Morgan 2007). The relationship between the streams and the aquifer may change in the future. Stream flow source areas were not included as part of the Designated Area or Project Review Area. As discussed in Section IV the Project Review area was based on Goal 11 exception areas which were based on developed areas or areas that may be developed in the future.

Designated and Project Review Areas – Reference Map

(This section should edited by organization submitting document depending on areas to be under petition)

The boundaries of the designated area represent geologic formations where the aquifer can be found. The project review area is smaller than the designated area and represents areas that are developed or may be developed in the future. The designated and project review areas are plotted on Plate 1.

APPENDIX A

References Cited

Aha consulting, 2015, City of La Pine, http://www.ci.la-pine.or.us/ (accessed June 2015)

Baird, B.D., 2016, Wastewater System Study Update For The City of La Pine, Oregon: Anderson Perry & Associates, Inc., City of La Pine, Job No. 33-06, p. 109. (in-text citation Baird, 2016b)

Baird, B.D., 2016, Water System Study Update For The City of La Pine, Oregon: Anderson Perry & Associates, Inc., City of La Pine, Job No. 33-05, p. 180. (in-text citation Baird, 2016a)

Campbell, Gracie, 2015, Deschutes Basin Board of Control, Swalley Irrigation District, http://www.swalley.com/deschutes.htm (accessed June 2015).

City of La Pine, 2015, Snapshot of the Water you Drink: City of La Pine, p. 2, http://www.ci.la-pine.or.us/sites/default/files/fileattachments/public_works/page/922/snap_shot_city_of_la_pine.pdf

City of La Pine, 2017, City of La Pine, http://www.ci.la-pine.or.us/ (accessed Feb 2017)

Cole, D. L., 2006, Groundwater Quality Report for the Deschutes Basin, Oregon, State of Oregon Department of Water Quality, 59 p.

Gannett, M.W., Lite, K.E., 2005, Simulation of Regional Ground-Water Flow in the Upper Deschutes Basin, Oregon: US Geological Survey, Water-Resources investigations Report 03-4195, p. 84.

Hinkle, S.R., Morgan, D.S., Orzol, L.L., Polette, D.J., Ground Water Redox Zonation near La Pine, Oregon: Relation to River Position within the Aquifer-Riparian Zone Continuum: US Geological Survey, Scientific Investigations Report 2007-5239, p. 30.

Ma, L., Madin, I.P., Olson, K.V., Watzig, R.J., 2009, Oregon Geologic Data Compilation: Oregon Department of Geology and Mineral Industries, http://navigator.state.or.us/sdl/data/OGDCv5.zip (accessed February 2017)

Morgan, D.S., Hinkle, S.R., Weick, R.J., 2007, Evaluation and Approaches for Managing Nitrate Loading from On-Site Wastewater Systems near La Pine, Oregon: US Geological Survey Scientific Investigations Report 2007-5237, 76 p.

Russell, P., Baggett, R., 2016, Goal 11 Exception Area: Exhibit A – Index Map to Ordinance 2016-007: Deschutes County, Oregon Department of Environmental Quality, p. 19.

Russell, P., Baggett, R., 2017, Goal 11 Exception: Deschutes County, Oregon Department of Environmental Quality, https://www.deschutes.org/cd/page/goal-11-exception (accessed February 2017)

Spurr, K., 2017, State kills $17M Wickiup Junction project: The Bulletin, http://www.bendbulletin.com/localstate/5683944-151/state-kills-17m-wickiup-junction-project (accessed March 2019).

US Bureau of Reclamation (USBR), 2016, US Bureau of Reclamation, Pacific Northwest Region, Major Storage Reservoirs in the Deschutes River Basin: US Bureau of Reclamation: https://www.usbr.gov/pn/hydromet/destea.html (accessed February 2017)

US Bureau of Reclamation, 2017, Reclamation: Managing Water in the West: Projects and Facilities: US Bureau of Reclamation, https://www.usbr.gov/projects/index.php?id=91 (accessed February 2017)

US Census Bureau, 2017, Profile of General Population and Housing Characteristics 2010 Demographic Profile Data, US Census Bureau, http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk (accessed February 2017)

APPENDIX B

USGS 12 Digit HUC

TABLE 3

USGS 12-DIGIT HYDROLOGIC UNITS

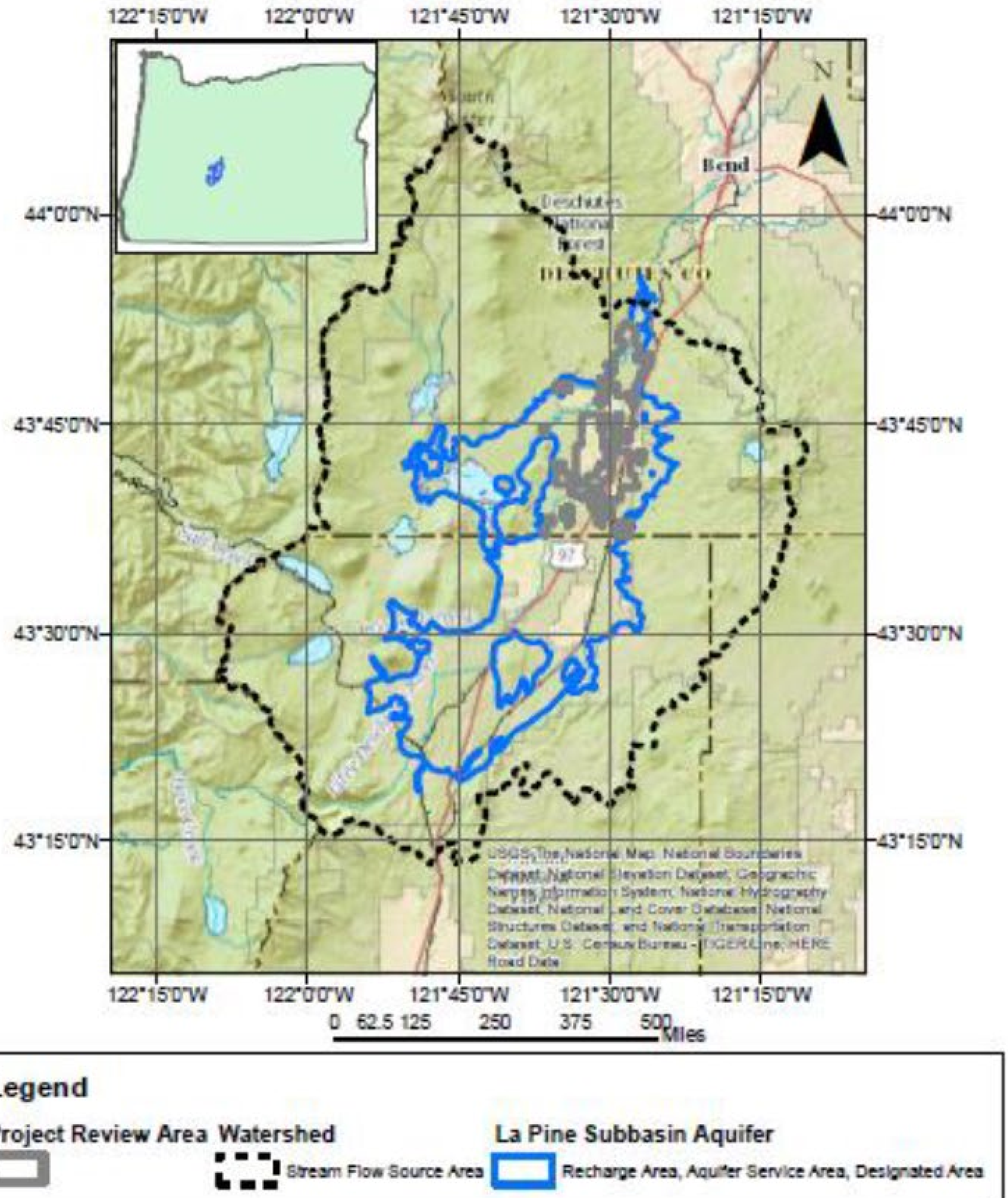
	HUC12	Name
Project Review Area	170703010301	Pringle Falls-Deschutes River
	170703010302	Fall River
	170703010305	Spring River
	170703010306	Deschutes Braid-Deschutes River
	170703020302	Cryder Butte-Little Deschutes River
	170703020303	Dorrance Meadow-Little Deschutes River
	170703020608	Paulina Peak South
	170703020609	Finley Butte-Long Prairie
	170703020701	Wickiup Junction
	170703020703	Lower Paulina Creek
	170703020704	Town of Lapine-Little Deschutes River
	170703020705	Kawak Butte-Little Deschutes River
	170703020706	Sugar Pine Butte-Little Deschutes River
Designated Area	170703010205	Browns Creek
	170703010206	Davis Creek
	170703010207	Wickiup Reservoir-Deschutes River
	170703020103	Little Odell Creek
	170703020104	Bunny Butte
	170703020105	Gilchrist Junction-Little Deschutes River
	170703020106	Town of Gilchrist-Little Deschutes River
	170703020206	Middle Crescent Creek
	170703020207	Lower Crescent Creek
	170703020301	Hamner Butte
	170703020404	Lower Sellers Creek
	170703020503	Marmot Butte

	170703020504	Fivemile Well
	170703020505	Crescent Butte
	170703020506	Walker Rim
	170703020603	Moffitt Butte
	170703020605	Town of Beal-Long Prairie
	170703020606	West Long Prairie
	170703020607	Surveyors Lava Flow
Watershed	170703010101	Soda Creek
	170703010102	Quinn Creek
	170703010103	Elk Lake
	170703010104	Snow Creek-Deschutes River
	170703010105	Cultus Creek
	170703010106	Deer Creek
	170703010107	Cultus River
	170703010108	Charlton Creek
	170703010109	Crane Prairie Reservoir-Deschutes River
	170703010201	Upper Odell Creek
	170703010202	Middle Odell Creek
	170703010203	Moore Creek
	170703010204	Lower Odell Creek
	170703010303	Siah Butte
	170703010304	Dutchman Creek
	170703010402	Town of Sunriver-Deschutes River
	170703020101	Clover Butte-Little Deschutes River
	170703020102	Hemlock Creek
	170703020201	Upper Big Marsh Creek
	170703020202	Lower Big Marsh Creek
	170703020203	Summit Lake
	170703020204	Crescent Lake
	170703020205	Upper Crescent Creek

	170703020401	Upper Sellers Creek
	170703020402	Sellers Marsh
	170703020403	170703020403
	170703020501	Corral Springs
	170703020502	170703020502
	170703020601	Stams Mountain
	170703020602	Green Butte
	170703020702	Upper Paulina Creek

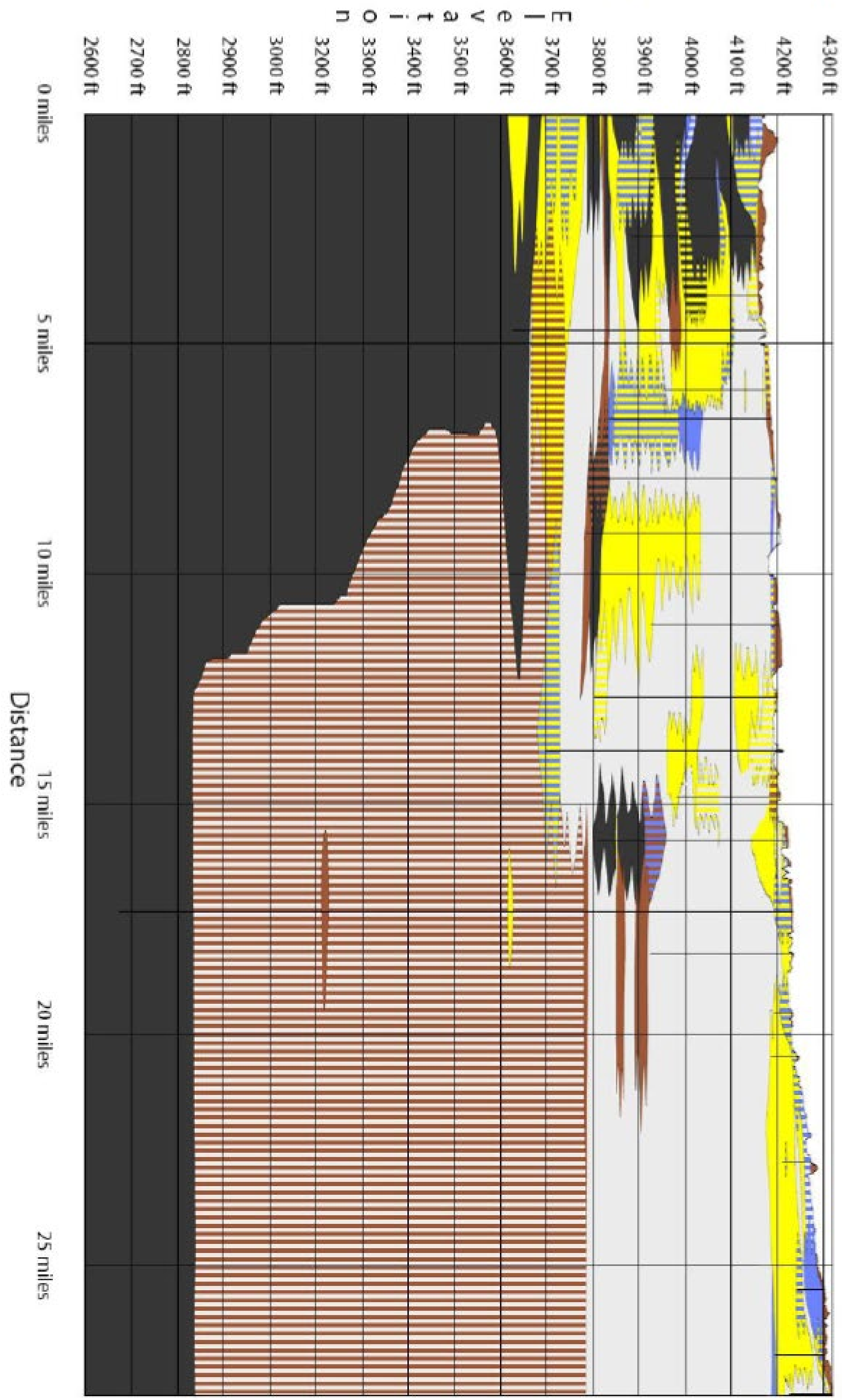
Note – All HUC 12 with in the SSAP are also within the La Pine Subbasin Aquifer Area. Both the SSAP and La Pine Subbasin Aquifer Area are within the Watershed/Stream Source Area for this aquifer.

Plate 1
La Pine Subbasin Aquifer
Sole Source Aquifer Designation Petition



David Cemanse, 2017, Plate 1: La Pine Subbasin Aquifer Sole Source Designation Petition. Oregon State University, p1Scale 1:100,000
Watershed generated from all water flowing past Benham Falls on the Deschutes River from -
Oregon Geospatial Enterprise Office, 2008, Oregon 10m Digital Elevation Model (DEM). Oregon Geospatial Enterprise Office
[illegible]
Aquifer Based on basin sediments from [illegible], 2009, Oregon Geologic Data Compilation. Oregon Department of Mineral Industries.
[illegible]
Petition Area Based on - Deschutes County Planning Commission, 2016, Exhibit A to Ordinance 2016-007 - Map. Deschutes County
[illegible]

Plate 2: North South Cross Section of La Pine Sub Basin Aquifer



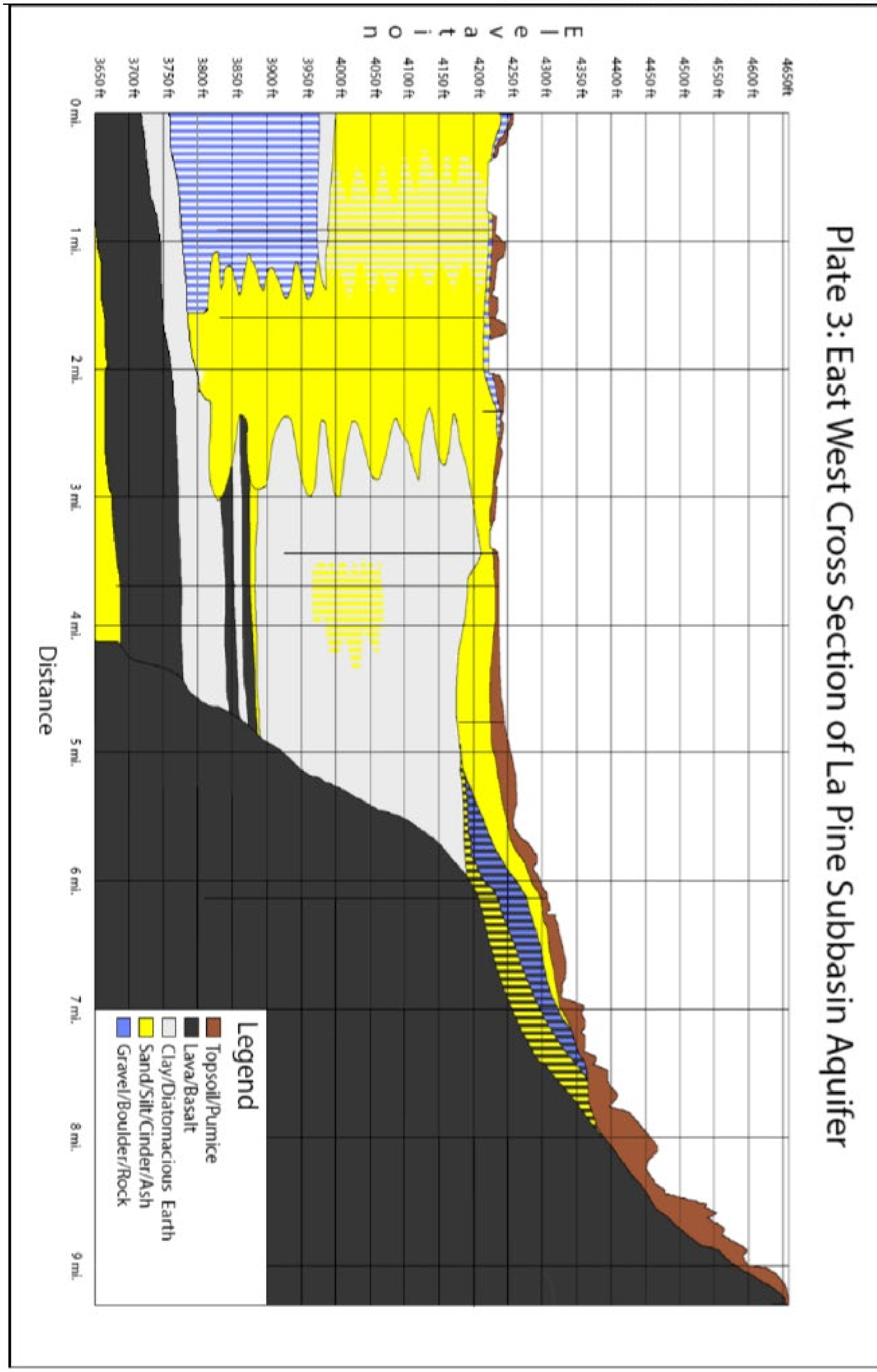


Plate 3: East West Cross Section of La Pine Subbasin Aquifer
Elevation
4650ft
4600 ft
4550 ft
4500 ft
4450 ft
4400 ft
4350 ft
4300 ft
4250 ft
4200 ft
4150 ft
4100 ft
4050 ft
4000 ft
3950 ft
3900 ft
3850 ft
3800 ft
3750 ft
3700 ft
3650 ft
0 mi.
1 mi.
2 mi.
3 mi.
4 mi.
5 mi.
6 mi.
7 mi.
8 mi.
9 mi.
Distance
Legend
Topsoil/Pumice
Lava/Basalt
Clay/Diatomacious Earth
Sand/Silt/Cinder/Ash
Gravel/Boulder/Rock