SURFACE-WATER CONTAMINANT ROUTING USING A DIGITAL STREAM INFORMATION SYSTEM

by

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Abstract. The U.S. Geological Survey is proposing to redesign its site-specific water-use data base into a topologic site-specific water-use data base that depicts water use as an integral part of the hydrologic cycle. The new data base is to be compatible with the theory of geographic information systems. By placing water use and other hydrologic data into a geographic information system framework, a stream information system can be developed. A stream information system allows a user to combine the spatial and topologic attributes of a basin with stream characteristics such as discharge, gradient, sinuosity, length, time-of-travel, and water use to develop models that simulate discharge, time-of-travel, supply and demand, and solute transport. An application of the stream information system is explored for the Umpqua River of southwestern Oregon. Here, most users rely on surface-water supplies, but these supplies are occasionally contaminated by tractor-trailer spills or by overflows of sewage treatment plants. Time-of-travel data are integrated into the stream information system to predict the time required for a contaminant to travel from a spill-site to a downstream user at a known value of discharge.

Key Words: Contaminant routing, geographic information systems, water-use data base, time-of-travel

I. INTRODUCTION

A perusal of the "Hydrologic Conditions and Water-related Events" sections of the U.S. Geological Survey's National Water Summary for 1985 and for 1986 indicates that the January 1988 oil spill in the Ohio River was a large-scale occurrence of a rather common event: pollution of rivers from accidental spills. From August 1983 to September 1985, more than 50 cases of stream contamination from spills were reported;

probably more cases were not reported. As the demands on water supplies increase, the consequences of these spills become more serious and the need to develop prevention and mitigation plans for hazardous spills becomes greater. Unfortunately, the financial resources for the development of these plans often are limited by more immediate needs, such as the cleanup of areas where spills have already occurred. Thus, any plans that are developed for the prevention or mitigation of spills need to be economically efficient and focus on high-risk target areas: areas downstream from possible spill sites, areas where alternative sources of water are limited, and areas where the economic ramifications of a spill are the greatest.

In the Umpqua River basin of southwestern Oregon (Figure 1), surface waters occasionally are contaminated by accidental spills of hazardous materials. According to the Oregon Department of Health, tractor-trailer accidents along the winding roads of the Umpqua River basin and Rogue River basin (the drainage immediately to the south) account for about 90 percent of such spills in the State (Boydston, 1988). In addition, power failures at sewage-treatment plants sometimes cause sewage to overflow into surface waters of the Umpqua Basin. To further complicate matters, summer flows in the basin are sometimes too low to provide adequate dilution. Since most of the population relies on surface water for drinking water, irrigation, and other uses such as livestock

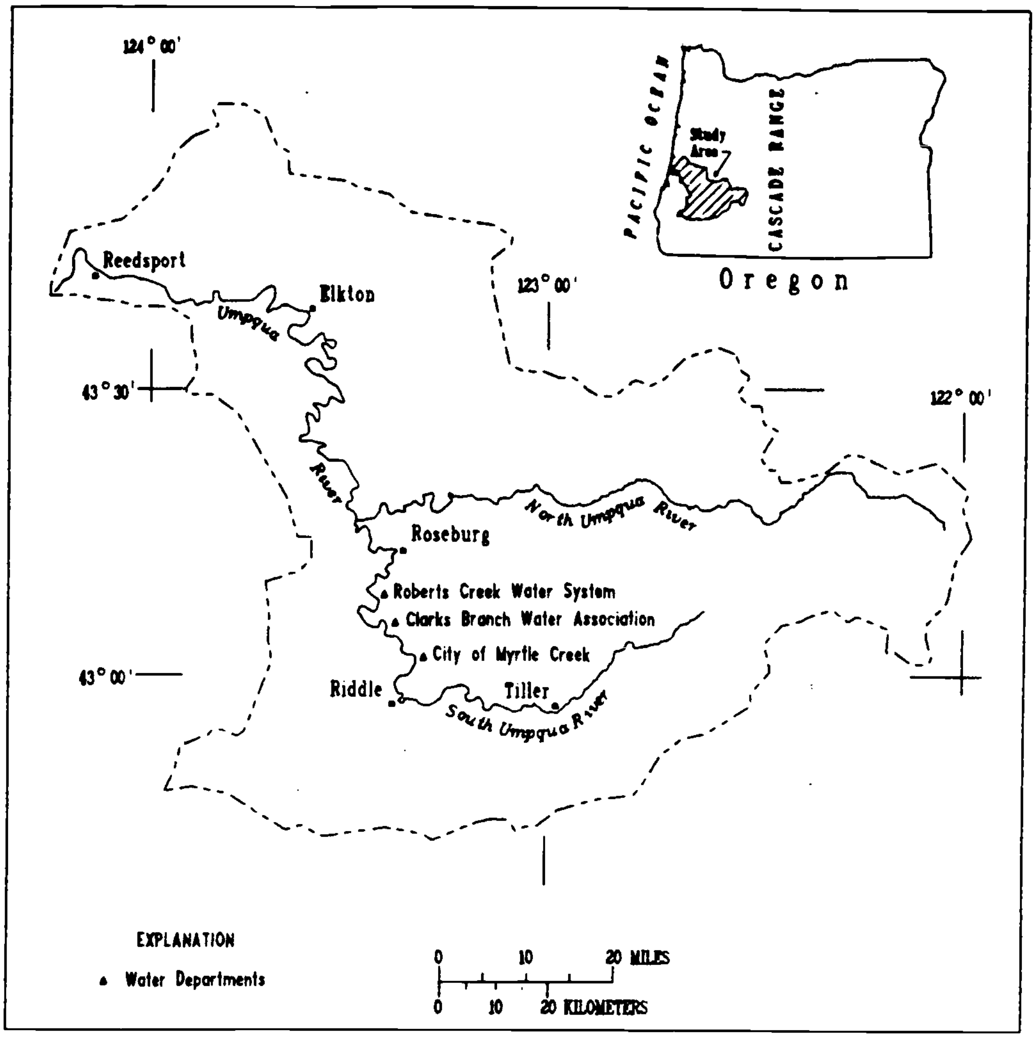


Figure 1.--Map of Umpqua River basin.

watering, the impact on water supplies resulting from contamination by an accidental spill could be substantial.

A stream information system (SIS) is a useful tool for determining areas where plans for the prevention or mitigation of spills are needed. Such a system combines the geographic display and analysis capabilities of a geographic information system (GIS) with the topologic and site-specific characteristics of a water-use data base. By using this combination, specific stream attributes (gradient, sinuosity, and length) and point attributes (stream discharge and water-use withdrawals) may be integrated with the spatial/topologic characteristics of a basin to develop models that simulate stream velocity, solute transport, and water supply and demand.

The objectives of this paper are to (1) describe how a GIS and a water-use data base can be integrated to build a SIS, and (2) show how additional attributes can be incorporated into the system to develop various models. In this paper, a simplified time-of-travel model has been constructed on the basis of time-of-travel values (the time a dissolved constituent takes to travel in a stream from one point to another) assigned to reaches of streams. This model predicts the time that the maximum concentration of a plume of dissolved contaminant takes to reach a downstream user for a given value of stream discharge.

Since the focus of this study is the design of the stream information system and not the prediction of travel times, several factors in the calibration and implementation of the model are de-emphasized. These factors are the calculation of stream width, the determination of the concentration and dilution of the contaminant as it moves downstream, the time required for the contaminant to pass an intake, and the determination of locations at which spills are most likely to occur.

II. SITE DESCRIPTION

The North and South Umpqua Rivers drain the west slope of the Cascade Range and then join to form the Umpqua River, which empties into the Pacific Ocean. This 4,640-square mile basin is characterized by steep hilly terrain and gently-sloping, rather narrow valleys. Most of the basin's 92,000 inhabitants live either in and around Roseburg or in Reedsport. With more than 85 percent of the basin in commercial forest, lumbering is the major industry. Some agriculture and mining are also found in the basin, although mining activity has greatly decreased since 1985 following the closure of the Nation's only nickel mine and smelter at Riddle. The rivers and streams of the basin provide an important habitat for steelhead trout and salmon; the need to protect this habitat increases the importance of maintaining good water quality.

Hydrology

The drainage basins of the North and South Umpqua Rivers are quite different geologically. The North Umpqua's headwaters are in the porous volcanic basalts typical of the Oregon Cascade Range; the South Umpqua's headwaters are in non-porous granites more typical of the Klamath and Siskiyou Mountains. Both basins receive equal amounts of precipitation. Because of the differences in geologic character, however, most precipitation in the North Umpqua drainage is stored as ground water, whereas most precipitation in the South Umpqua drainage runs off to streams (Phillips and others, 1965). Because of ground-water storage, and partially because of storage from power-supply reservoirs, the range of flow in the North Umpqua River is considerably less than in the South Umpqua River. Near the confluence of the two rivers, the ratio of the maximum monthly mean discharge to the minimum monthly mean discharge for the North Umpqua is 7-to-1 (6,983 to 984 ft^3/s [cubic feet per second]), but it is 58-to-1 (7,368 to 128 ft^3/s) for the South Umpqua (Friday and Miller, 1984).

Water Use

Three-fourths (69,000) of the Umpqua River basin's inhabitants are served by public-water-supply systems, all of which rely on surface water and several of which rely solely on the South Umpqua River. Because of the low flows in the South Umpqua River, the City of Roseburg, the basin's largest public-water-supplier, withdraws its water from sources in the North Umpqua River basin. Almost 100 percent of the water used for industrial purposes in the Umpqua River basin comes from surface water. The largest use of industrial water is by the forest products industry.

Because of the ruggedness of the terrain, arable lands exist only along the valley bottoms. Approximately 47,000 acres of land are farmed, 16,000 (36 percent) of which are irrigated. Hay and silage make up most (87 percent) of these irrigated crops. Roughly 95 percent of the water supply for irrigation comes from surface water (U.S. Geological Survey, 1987). Sixty percent of irrigated lands are located in the South Umpqua River basin; therefore, when flows become low during the summer, junior (recently-filed) water rights commonly are not met.

III. METHODOLOGY

The development of the SIS is a four-step process: the creation of GIS coverages (digital map files), the integration of the water-use data base, the incorporation of time-of-travel values, and the assignment of time-of-travel values.

Creation of GIS Coverages

A GIS is a configuration of hardware and software which operates on a geographic data base to analyze individual data-base elements or to synthesize multiple data-base elements (Robinove, 1986). The type of GIS used in this study is a vector-based GIS known as ARC-INFO. For digital maps of features such as stream networks, ARC-INFO depicts each stream segment as an arc. Each end point of the arc has a node, and direction along the arc can be implied using the from-node/to-node notation (Figure 2). Arcs also can

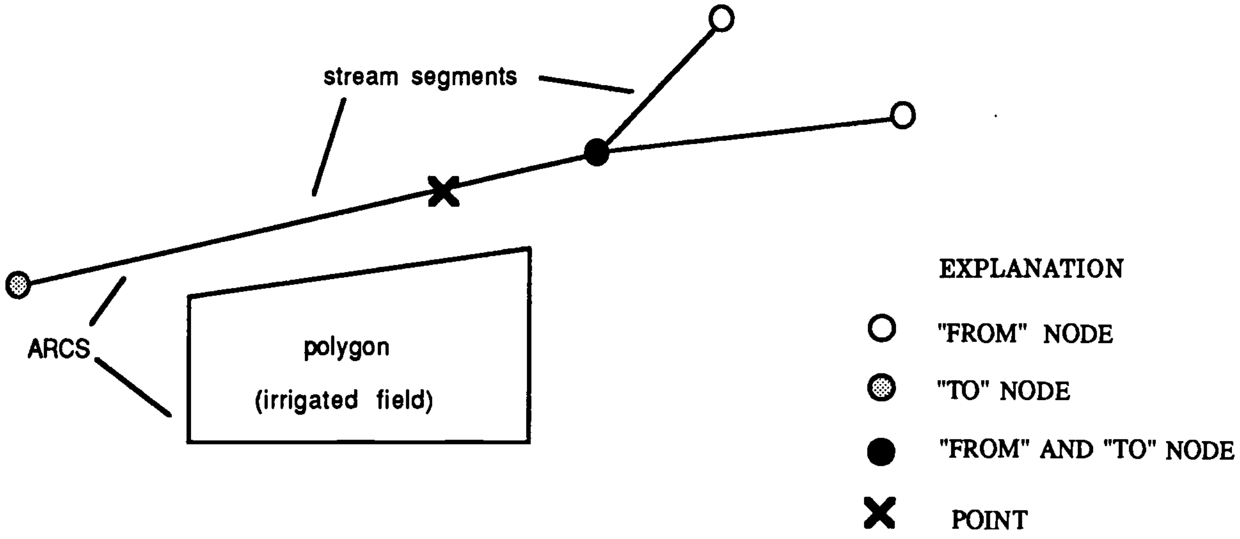


Figure 2.-- Geographic Information System schematic diagram of stream segments and irrigated fields.

describe the outline of polygons such as irrigated fields or water-supply service areas. Points are used to describe features such as withdrawal and return locations. Attributes can be assigned to points, arcs, or polygons. These attributes could include latitude-longitude for points, length for arcs, or area for polygons.

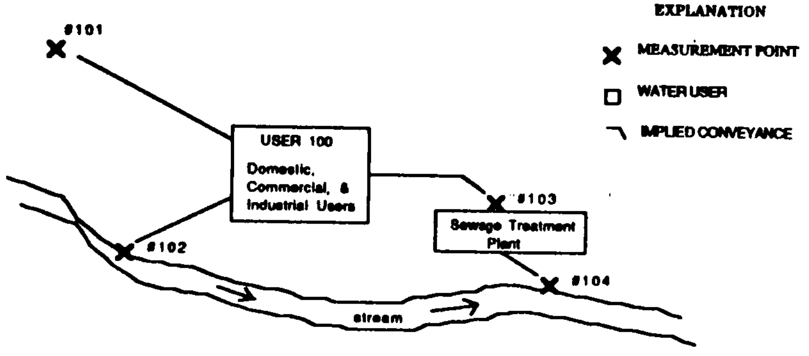
The coverages used for this project are from the 1:100,000 digital hydrography series of the U.S. Geological Survey. Each of these coverages was scan-digitized so that most hydrographic features found on the paper map at that scale also are found on these digital maps.

Integration of the Water-Use Data Base

The U.S. Geological Survey is proposing to redesign its site-specific water-use data base for the National Water-Use Program into a topologic site-specific water-use data base with the ability to integrate water use into the hydrologic cycle. This integrated data base would build on the traditional Geological Survey point water-use data base known as SWUDS (State Water-Use Data System) by providing a simulated, rather than implied, link between measurement points.

In the SWUDS data base, measurement points presently are linked to a particular water user by a common identifying (User-ID) number. The diagram in Figure 3a shows how a hypothetical municipal water supplier (User-ID number 100) would be represented. Ground water is withdrawn at point 101 and surface water at point 102. Used water is released to a sewage treatment plant at point 103 and returns to the stream at point 104. Three files contain information on the user and on the conveyances and measurements associated with each user. The HEADER file contains data on the user: Name, Address, Phone, City, and type of Use. The CONVEYANCE file contains data on the type of Action (withdrawal or return), the Source of water (ground, surface, or transfer), and the location of the point (Latitude-Longitude or Township-Range). Monthly and annual water-use data associated with each measurement point are stored in the MEASUREMENT file.

The lines that connect the measurement points and the



HEADER File

User-ID
Number = 100
Name = Salmon Water District
Address = 301 N. Main
City = Oceanview
Phone = 231-2298
Use = Water Supplier

CONVEYANCE File

User-ID
Number = 101
Action = Withdrawal
Source = Ground water
Latitude = 45° 23' 45"
Longitude = 124° 22' 22"

User-ID
Number = 102
Action = Withdrawal
Source = Surface water
Latitude = 45° 21' 20"
Longitude = 124° 40' 45"

User-ID
Number = 103
Action = Release
Source = Sewage treatment
Latitude = 45° 21' 33"
Longitude = 124° 35' 33"

User-ID
Number = 104
Action = Return
Source = Surface water
Latitude = 45° 21' 05"
Longitude = 124° 35' 40"

MEASUREMENT File

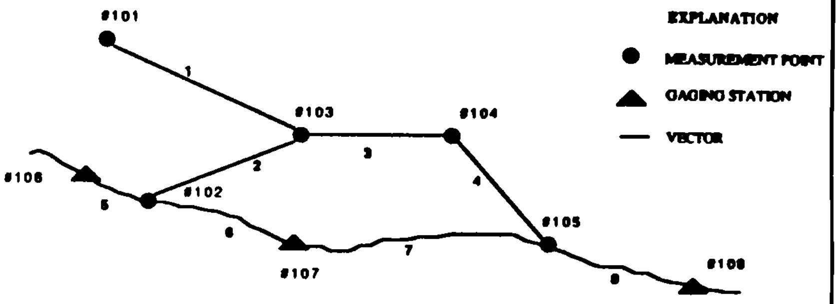
User-ID
Number = 101
Month = 5
Year = 85
Quantity = 45.7
Units = MGD

User-ID
Number = 102
Month = 5
Year = 85
Quantity = 67.9
Units = MGD

User-ID
Number = 103
Month = 5
Year = 85
Quantity = 98.7
Units = MGD

User-ID
Number = 104
Month = 5
Year = 85
Quantity = 95.3
Units = MGD

Figure 3a.--Diagram of geographic configuration and State Water-Use Data base (SWUDS) structure for a hypothetical water-supply system.



WATER USER File

Facility-id = 100
Owner = Salmon W.D.
Street = 301 N. Main
City = Oceanview
Phone = 231-2298

POINT LOCATION File

Facility-id = 100
Point-id = 101
Latitude = 45° 23' 45"
Longitude = 124° 22' 22"
Point-type = Withdrawal
Water-type = Ground

Facility-id = 100
Point-id = 102
Latitude = 45° 21' 20"
Longitude = 124° 40' 45"
Point-type = Withdrawal
Water-type = Surface

Facility-id = 100
Point-id = 103
Latitude = Unknown
Longitude = Unknown
Point-type = Junction
Water-type = Mixed

Facility-id = 0
Point-id = 107
Latitude = Unknown
Longitude = Unknown
Point-type = Junction
Water-type = Surface

USE-VECTOR File

Vector-id = 1
From-pt-id=101
To-pt-id=103
Use =Water supply
Vector-type=convey

Vector-id =2
From-pt-id=102
To-pt-id=103
Use =Water supply
Vector-type=convey.

Vector-id =3
From-pt-id=103
To-pt-id=104
Use =Water supply
Vector-type=process

Vector-id =4
From-pt-id=104
To-pt-id=105
Use =Sewage treat.
Vector-type=process

Vector-id =5
From-pt-id=106
To-pt-id=107
Use =none.
Vector-type=convey.

MEASUREMENT File

Vector-id= 1
Direction= From
Month = 5
Year = 85
Quantity =45.7
Units = MGD

Vector-id= 2
Direction=Both
Month =5
Year =85
Quantity =67.9
Units = MGD

Vector-id=3
Direction=From
Month = 5
Year =85
Quantity =110.8
Units = MGD

Vector-id= 3
Direction= To
Month = 5
Year =85
Quantity =75.6
Units = MGD

Figure 3b.--Diagram of geographic configuration and proposed integrated water-use data base structure for a hypothetical public water-supply system. NOTE: Not all points and vectors are included in the example data base.

boxes representing the water users in Figure 3a are implied; thus, there is no easy way to simulate the routing of water from one point to another. Without such simulated routing, there is no way to integrate the user with the hydrologic cycle so that a stream network, complete with offstream withdrawals and returns, can be geographically represented in a digital format.

The proposed topologic site-specific water-use data base, however, uses the arc-node topology of ARC-INFO (shown in Figure 2) to provide a simulated link between measurement points. The measurement points are still represented by points at specific locations, but all other information, such as system ownership and conveyance, are tied to arcs.

In the hypothetical municipal water system example in Figure 3b, the WATER USER file is similar to the HEADER file in the SWUDS data base (Figure 3a). The Facility-id, which serves as the common identifying number (number 100), is equivalent to the User-ID number, and one record of general information is supplied for each facility. Water-use type however, is associated with the USE-VECTOR file. (This file will be explained later in the discussion.) The POINT LOCATION file is similar to the CONVEYANCE file; locational information, along with the type of action (Point-type) and source of water (Water-type), is stored for each point.

The major difference between the two data bases is that in the proposed system, the vectors, or arcs, link the points.

These vectors can be thought of as pipes carrying water. Each pipe has data in the USE-VECTOR file showing the point at which it began and ended, allowing direction along the pipe to be specified. The type of water use (for example, domestic, industrial, irrigation) along that pipe is also stored in the file. By associating the type of water use with the vector, rather than with the facility, data retrievals and summations of water-use data for various use types within a facility (for example, sewage treatment) easily can be made. Associating use with the vector also allows vectors representing a water-use distribution system to be differentiated from vectors representing streams. The vector representing the location at which the water is actually being used (processed) rather than conveyed is shown by the Vector-type field. Use also may be assigned to vectors representing streams to show in-stream uses.

Measurement data are associated with the endpoints of vectors in the proposed data base. The Direction field in the MEASUREMENT data file determines whether the measurement represents water coming into or out of the pipe. By comparing dates and quantities with Vector-ids, losses or gains can be calculated along the pipe.

This data structure also can be applied to a stream network, with arcs representing stream reaches and points representing measurement locations. Thus, by being able to store both water-use information and streamflow data in the data base, the proposed system can better incorporate selected water-use characteristics into the hydrologic cycle. Water can then be tracked through its entire drainage area and the effects of user withdrawals and returns can be integrated into the stream network.

The data base management system used for this data base is relational, meaning that one record from one data file may relate or join to one or several records in another file. Thus, as long as each data file has a common field (facility, vector, or point-id), various pieces of information associated with that point or vector can be matched. Such information might include stream discharge data, the number of acres in a field, or the permit number and level of treatment for a waste water plant.

Incorporation of Time-of-Travel Values

The data used to assign travel times to each arc were gathered from time-of-travel studies done in the Umpqua River basin by the U.S. Geological Survey and the Oregon State Water Resources Board (now Oregon Water Resources Department) in the early 1960s. It should be noted that in 1964, a flood approximating a 100-year event that occurred in the basin may have altered some of the channel characteristics (Harris and others, 1979). However, the effects of this flood on channel geometry and the resulting changes in travel-time cannot be obtained without considerable additional field work. For the demonstration purposes of this paper, pre-1964 channel geometry will be assumed.

The Geological Survey studies were made in April and May of 1963 during medium and high flows on the South Umpqua River and on the Umpqua River between Tiller and Elkton. For the medium flow study, discharge at the stream gage at Tiller was 927 ft^3/s; for the high flow study, discharge at the Tiller gage was 1,900 ft^3/s. Rhodamine B dye, used as a tracer, was injected into the stream and was detected downstream at selected sites using a fluorometer. These samples were taken at intervals frequent enough to determine the dye peaks, or points of maximum concentration, downstream from the injection site. Discharge was measured at most of the sampling sites, and for sites that were not measured, interpolations were made on the basis of time lags and change in stage (Harris and Sanderson, 1968).

A low-flow study (discharge at Tiller, 190 ft^3/s) was made in October and November 1962 by the Oregon State Water Resources Board on the South Umpqua and Umpqua Rivers between Tiller and Elkton. Rhodamine B dye was also used, but downstream detection was made visually rather than with a fluorometer. The travel times associated with low flows, therefore, were not concentration peaks, but rather the visible leading edge of the tracer (Harris, 1963). For the medium flow study, travel times for the leading edge of the tracer were generally about 50 percent faster than those of the concentration peak. Since this paper is for demonstration purposes, however, low-flow travel times for the leading edge will be considered equal to low-flow travel times for the concentration peak.

Assignment of Time-of-Travel Values

The information obtained from the time-of-travel studies was used as a basis for developing a simplified time-of-travel model that calculates travel times for discharges different from those observed directly in the field. This model was constructed only for those reaches with available field data (South Umpqua and Umpqua Rivers). In the future, regression equations will be used to expand this simplified model to predict travel-times for streams in the basin without field data. Before the simplified model could be constructed, however, several preliminary steps had to be taken.

First, each arc representing a reach of stream for which time-of-travel data were available was separated into 1-mile segments. This manipulation facilitated regression equations by making length a common variable for each arc.

Next, stream sinuosity and gradient were calculated for each 1-mile segment of stream. Sinuosity is defined as the actual length of a stream segment divided by the straight-line distance between the end points of each stream segment. Gradient is defined as the change in the altitude of the stream channel segment divided by the length of the channel segment.

The field sample sites used to determine time-of-travel values for stream segments were generally more than 1-mile apart. Consequently, the river mile designation for each sample site was rounded off to the nearest mile; then the arcs in the coverage that represented the 1-mile segments between sample sites were grouped together and given the appropriate travel-time value. For example, in Figure 4, sample site 1 is at river mile 1.4 and sample site 2 is at river mile 3.8. Site 1, therefore, is rounded off to river mile 1.0 and site 2 is rounded off to river mile 4.0. Segment 1 is then assigned the time-of-travel value associated with the river reach downstream of sample site 1, while segments 2,3, and 4 are grouped together and assigned the time-of-travel value for the river reach between sample sites 1 and 2.

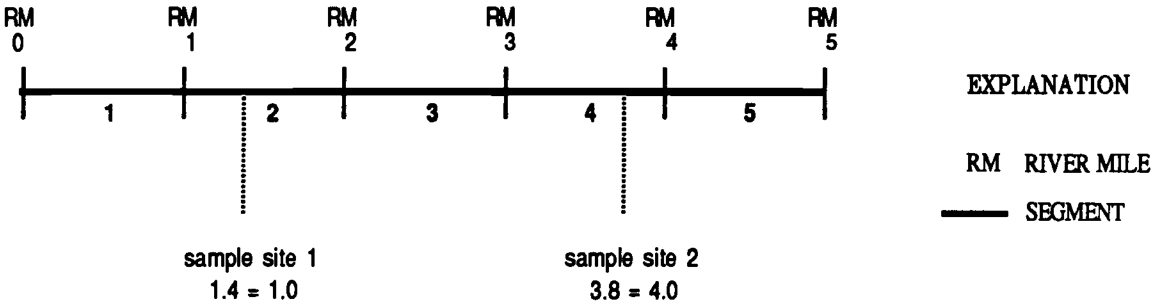


Figure 4.-- Methodology for rounding off sample sites to the nearest whole river mile

This grouping of arcs and assigning of travel times gave rise to the possibility that consecutive arcs in a grouping might have different gradients and sinuosities, but the same travel time. For example, segment 4 might have a different gradient and sinuosity than segments 2 and 3; thus when gradient and sinuosity variables are used in a regression equation to calculate travel time, some skewing of the results might occur. Therefore, an average sinuosity and gradient was determined for each grouping of arcs assigned the same travel-time value. In Figure 4, segments 2, 3, and 4 would be assigned the average sinuosity and gradient of the 3 segments because they were grouped together and given the same travel time.

IV. CONSTRUCTION OF TIME-OF-TRAVEL MODEL

Once the base data were assigned to each segment (arc) of the South Umpqua and Umpqua Rivers between Tiller and Elkton, discharge (Q) was plotted against travel rate (V) on a semi-log graph for each stream segment (Figure 5). Discharge was obtained from the field studies and travel rate was obtained by dividing the travel time of the contaminant peak between sample points by the distance between the sample points. This technique was used by Harris (1968). Since the relationship between discharge and travel rate on the graph was generally linear, an equation was developed to approximate

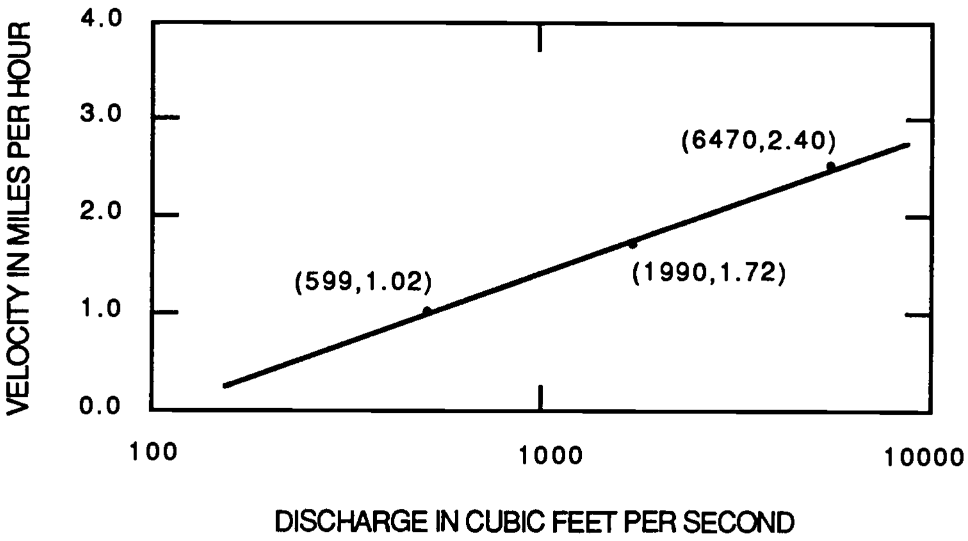


Figure 5.-- Rate of travel for South Umpqua River (river mile 47 to river mile 48).

each line. For the stream segment in Figure 5, the equation for the line was:

$$(1) \quad V = (1.327) \times (\log_{10} Q) - 2.65$$

With a discharge of 1,000 ft^3/s, the travel rate for the reach between river mile 47 and 48 is estimated to be 1.33 mi/hr (miles per hour). Since this segment is 1 mile long, a contaminant slug would take approximately 0.75 hours to pass along the segment.

In an attempt to determine time-of-travel information for streams in the basin where no time-of-travel data exist, a multiple linear regression equation was developed. This equation was derived by regressing the travel-time values of all segments of the South Umpqua and Umpqua Rivers (Tiller to Elkton) against the discharge, gradient, and sinuosity of all segments.

This initial attempt at developing a multiple linear regression equation demonstrated that the determination of travel times for streams without travel-time values will probably require grouping of stream segments and incorporation of an additional independent variable. The best fit equation was

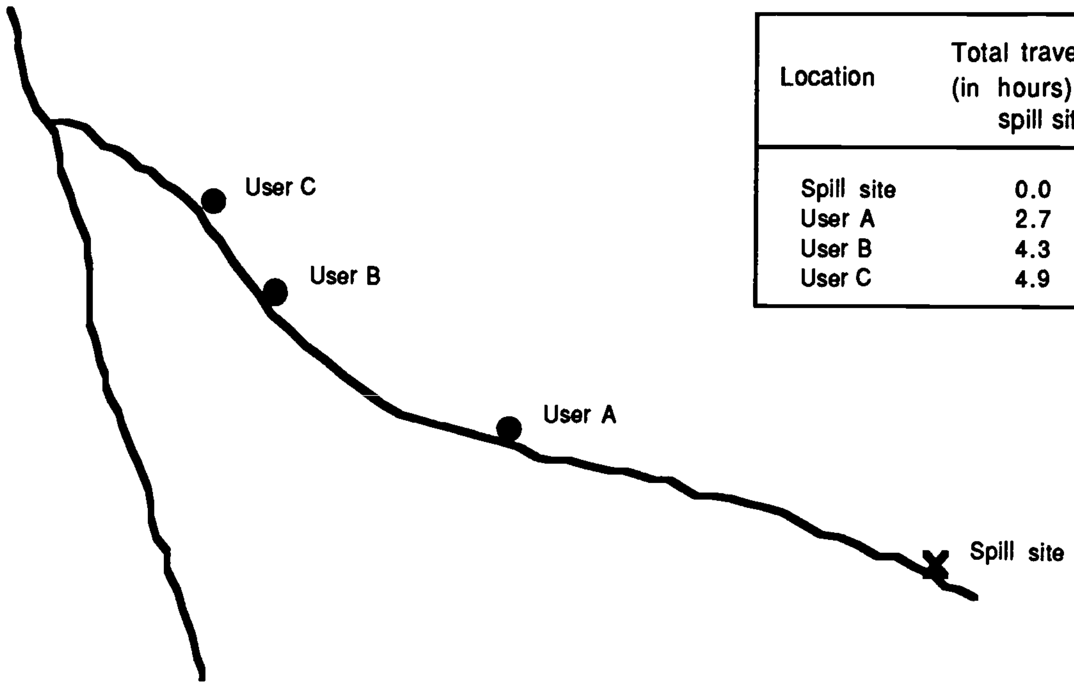
$$(2) \qquad y = -2.51 + 1.14676\ (\log_{10} x) + 81.64z$$

where y equals travel time in mi/hr, x equals discharge in ft^3/s, and z equals gradient in ft/mi (feet per mile). The coefficient of determination (r^2) for equation 2 was only 0.50. Sinuosity was dropped as a variable from the equation because there was no statistical relationship between travel time and sinuosity. In other words, the coefficient (β) of the independent variable (sinuosity) cannot be proven to be greater than 0 for alpha equals 0.05. In an attempt to improve the equation in future studies, the stream segments will be grouped by gradient. Equations will then be developed for stream segments within the groupings. In addition, a variable for channel width will be added to the equation. A close approximation of this value should be attainable from large-scale aerial photos.

V. GENERATION OF TIME-OF-TRAVEL MODEL

The simple linear equations for each 1-mile stream segment between Elkton and Tiller were used to generate a time-of-travel model that predicts travel times between points along the South Umpqua and Umpqua Rivers. For a given discharge, the travel times along each segment were calculated from the equations. These calculated values were then integrated with ARC-INFO's NETWORK package so that streamflow routing could be done and the travel-times summed.

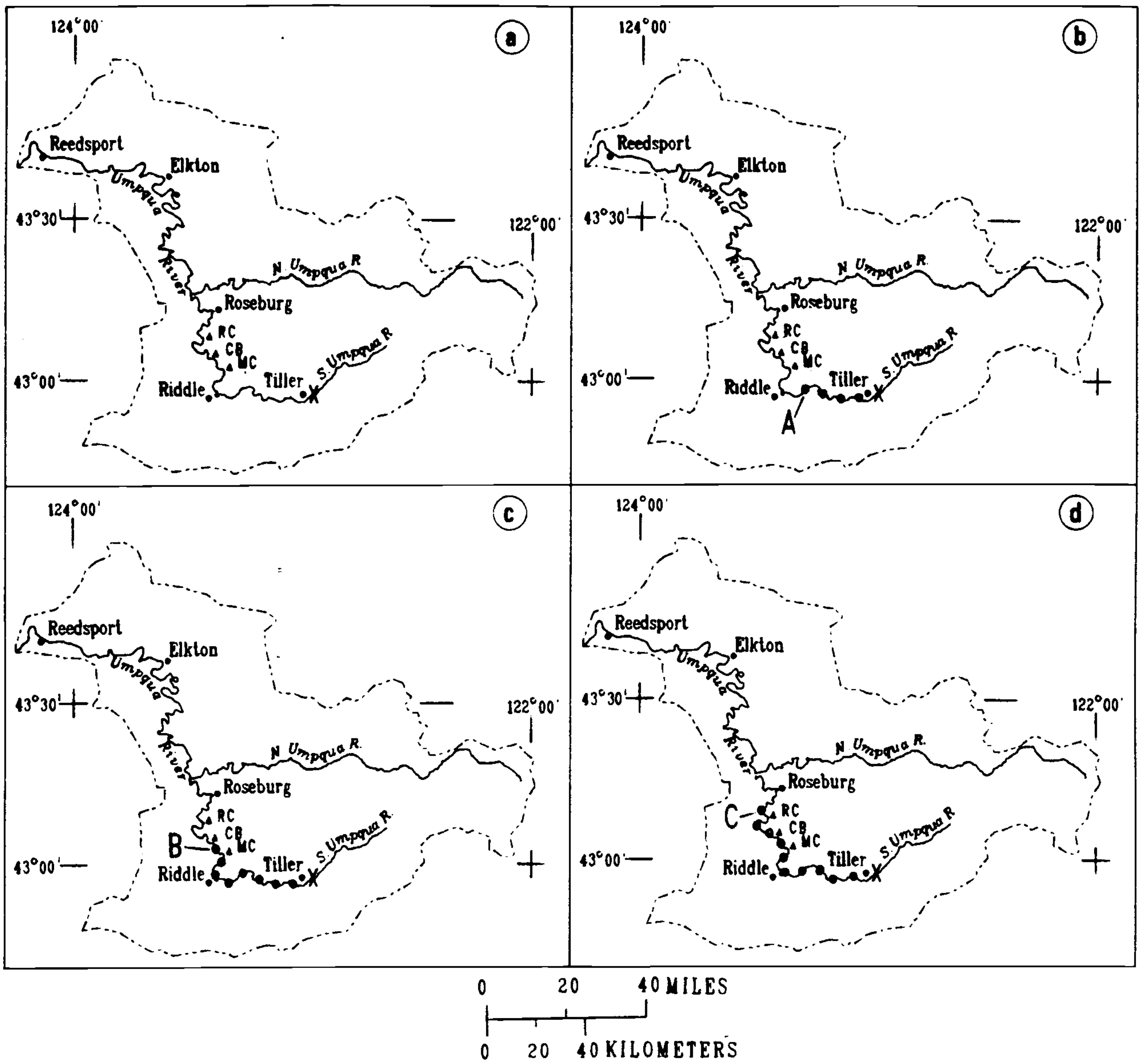
The NETWORK package allows a user to interactively add points to a stream coverage and then sum the time required to travel along the streams between the two points. In the application of this study, a beginning point representing a hypothetical spill site is added, along with an end point representing the mouth of the stream. ARC-INFO automatically routes downstream and cumulatively totals the time required to reach each arc end point. By comparing the routed stream network and its cumulative time values with withdrawal points from the water-use data base, the time of travel between spill site and a water user for a known value of discharge is determined (Figure 6).



Location	Total travel time (in hours) from spill site
Spill site	0.0
User A	2.7
User B	4.3
User C	4.9

Figure 6.-- Example of stream flow routing and cumulative totaling of travel times by ARC-INFO's NETWORK package

An actual application of the time-of-travel model is shown in Figures 7a through 7d. A hypothetical spill from a tanker-truck accident occurs at point X (river mile 75) near Tiller in Figure 7a. Assuming that the discharge at the gage at Tiller is 1,000 ft^3/s, the peak flow of the contaminant would arrive downstream at point A (river mile 54) in 15 hours (Figure 7b), at point B (river mile 35) in 30 hours (Figure 7c), and at point C (river mile 21) in 45 hours (Figure 7d). The contaminant slug peak would reach the intakes at the City of Myrtle Creek, at the Clarks Branch Water Association, and at the Roberts Creek Water System in approximately 25.6 hours, 30.2 hours, and 42.2 hours respectively.



Explanation

▲ Water Departments

RC Roberts Creek Water System
CB Clarks Branch Water Association
MC City of Myrtle Creek

X Site of Hypothetical Spill

-●-●-●-●- Travel Route of Contaminant

	River mile from mouth	Arrival time of contaminant (hours)	Distance from contaminant source (miles)	Average velocity from contaminant source (mi/hr)
Point X	75.0	0.0	0.0	—
Point A	54.0	15.0	21.0	1.40
City of Myrtle Creek	39.6	25.6	35.4	1.38
Point B	35.0	30.0	40.0	1.33
Clarks Branch Water Association	34.6	30.2	40.4	1.34
Roberts Creek Water System	22.6	42.2	52.4	1.24
Point C	21.0	45.0	54.0	1.20

Figure 7.--Maps and table showing contaminant movement from a hypothetical spill in the South Umpqua River near Tiller, Oregon; (a) location of hypothetical spill (point X), (b) location of contaminant (point A) 15 hours after hypothetical spill, (c) location of contaminant (point B) 30 hours after hypothetical spill, (d) location of contaminant (point C) 45 hours after hypothetical spill. Discharge at the Tiller gage is 1,000 cubic feet per second.

VI. COMPUTER REQUIREMENTS

A major consideration in the setup of a SIS is the amount of disk storage space required. For a complete SIS of a basin the size of the Umpqua, at a scale of 1:100,000, 40 megabytes of disk space are needed to store the software and the data. Thus, a SIS can be run on most personal computers with 40 megabytes of hard disk, although additional disk space would be preferable.

The amount of disk space could be decreased somewhat by using stream segments longer than 1 mile. However, some precision in the calculation of travel times would be lost owing to the increase in distance between the water-use point along the arc and the node point of the arc for which the travel-time data is actually calculated.

VII. SUMMARY

The integration of GIS and the topologic water-use data base into a stream information system should prove to be an effective means of handling a problem such as contaminant routing. A beneficial feature of this system is that water may be routed through an entire stream network and the effects of withdrawals and returns from streams may be incorporated into the network. In addition, the relational data structure of the SIS allows additional data files and data layers to be easily added, thus providing greater flexibility.

VIII. ADDITIONAL APPLICATIONS

The most obvious additional applications for this SIS are (1) the determination of the dilution of the contaminant as it moves downstream and (2) the total time that a user would be unable to use an intake owing to a spill. Some of this information could be determined by plotting (as in Figure 5) the dilution information obtained during the medium and high-flow studies. Information regarding the behavior of the potential contaminants in water also needs to be considered as a factor in order to fully calibrate the model.

An important area for further analysis is the determination of hazardous areas: where spills are most likely to occur and where the damage would be the greatest. One factor in determining possible spill sites is, of course, the location of sewage treatment plants. Traffic volume data and accident reports could be used to determine potential accident sites. Because of its ability to show the geographic relationships of water users to features such as streams, roads, and other water users, the SIS could also assist in the determination of the availability of alternative water supplies for downstream users and the economic effects of having to develop these alternative sources.

The use of a GIS for displaying hazard-potential information could help decision makers determine where actions for the prevention or mitigation of spills need to be taken or strengthened and could provide a framework from which to which to answer such questions as:

Is it cheaper to fix the road to make it safer or to provide an alternative source of drinking water?

Does a new sewage-treatment plant need to constructed or does the existing one simply need to be enlarged?

Would there be enough dilution potential to provide fish protection in case of a spill?

IX. REFERENCES

Boydston, Jim. 1988. Personal Communication. 8 Feb.

Friday, John and Miller, S.J. 1984. Statistical summaries of streamflow data in Oregon, volume 2, Western Oregon. U.S. Geological Survey Open-File Report 84-454, Portland.

Harris, D.D. 1963. Umpqua River basin time-of-travel study. Unpublished Paper. U.S. Geological Survey, Portland.

-----. 1968. Travel rates of water for selected streams in the Willamette River basin, Oregon. U.S. Geological Survey Hydrologic Investigations Atlas HA-273, Washington.

Harris, D.D. and Sanderson, R.B. 1968. Use of dye tracers to collect hydrologic data in Oregon. Water Resources Bulletin 4:51-68.

Harris, D.D., Hubbard, L.L. and Hubbard, L.E. 1979. Magnitude and frequency of floods in western Oregon. U.S. Geological Survey Open-file Report 79-553, Portland.

Phillips, K.N., Newcomb, R.C., Swenson, H.A., and Laird, L.B. 1965. Water for Oregon. U.S. Geological Survey Water-Supply Paper 1649, Washington: G.P.O.

Robinove, C.J. 1986. Principles of logic and the use of digital geographic information systems. U.S. Geological Survey Circular 977, Denver.

U.S. Geological Survey. 1985. National water summary, 1984, hydrologic events, selected water-quality trends, and ground-water resources. U.S. Geological Survey Water-Supply Paper 2275, Washington: G.P.O.

-----. 1986. National water summary, 1985, hydrologic events and surface-water resources. U.S. Geological Survey Water-Supply Paper 2300, Washington: G.P.O.

-----. 1987. Water-Data Storage and Retrieval System (WATSTORE), Portland.