Conceptual Patterns for Water Resources Information Systems

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ABSTRACT

Water Resources Information Systems (WRIS) present different types of problems during the data storage and analysis phases, related with the complex nature of the environmental data spacio-temporal phenomena. There are many questions to deal with, such as geographic representation of environmental variables, large time-series management, measurements and observations related with different hydrologic phenomena recording and the integration of simulations models to information systems.
Conceptual models allow us to understand and simplify problems in a specific domain. These problems can be expressed through analysis patterns, which reflect conceptual structures of an application domain speeding up the development of the abstract analysis model. This model will be able to capture the main requirements from real world problems. This type of patterns, are used in the present paper to define conceptual microarchitectures that allow the appropriate representation of environmental information in WRIS. Accordingly, the physic domain environmental objects are initially identified and an architecture style is defined, allowing this way the integration of WRIS with another interacting systems. The representation of the hydrological phenomena spatial component, is made by means of the conceptual Framework GeoFrame specialization.

KEYWORDS: analysis patterns, conceptual model, water

1. INTRODUCTION

Water Resource Information Systems (WRIS) are concerned with the management about different interacting components of the environment: surface and underground water, soil, air, living species and human actions. They embrace a great diversity of problems and functionality related with topics such as: water resources planning, flood prediction, mitigation of contamination, licensing of abstractions, etc. WRIS include different kinds of computational programs ranging from data base management to simulation models: hydrometeorological data base management, statistical analysis packages and hydrological simulation models for different physical process, such as rainfall-runoff, surface water quality, sediment transport, risk assessment, flood prediction, groundwater, etc. The aim of prediction using models is to improve decision-making about an hydrological problem [3].

Environmental problems are spatially distributed and dynamic and they are characterized by the complexity of the underlying processes. To be useful for the support planning and decision making processes, environmental data have to be transformed into information that meets the requirements of these processes [7].

Normally, data flow for these systems can be structured in four phases: data capture from real world, data storage, data analysis and metadata management [12].

The term *data capture* denotes the process of deriving environmental data objects from environmental objects. Then, the first step in WRIS data processing is the mapping of the objects from the real world into abstract entities that can be handled by computers.

Because of the complexity and heterogeneity of environmental data, during the *data storage* phase one of the main problems is to chose appropriate conceptual structures to optimize overall system performance.
There are many sources of complexity in the living world, such as: large amount of data to be processed, highly distributed data, uncertainty, etc. This paper mainly focuses in the requirement of *spatio-temporal data management*. Environmental objects have a location, a spatial extension and change over time [12]. This question implies to solve problems such as environmental data geographic representation [11], the management of different physical variables large time-series and the recording of measured and observed phenomena. Geographic Information Systems (GIS) are used for capturing, storing, processing analyzing and visualizing geo-referenced data [12]. The growing utilization of this systems in environmental organizations and the benefits provided by them [3], also state the requirement of integration in a GIS conceptual framework for a WRIS conceptual model.

During the analysis data phase, models of different types provide a means of quantitative extrapolation or prediction that allow to simulate states of a real hydrological system from available measurements in space and time where measurements are not available and into the future, to asses the likely impacts of hydrological changes [3].
Normally, there are many types of models available in water resources organizations, but current computational models of hydrologic systems are, for the most part, isolated from each other. This is because simulation models software has not been developed in an integrated context of information systems, taking benefits of the information, tools and interactions existing in them. There are not still conceptual models that allow the integration of simulation models with information systems.
Recently, a new trend is emerging where GIS systems are combined with analytical, mathematical models to form spatial decision support toolkits. In these integrated systems the GIS is used to handle the spatial data and provide a user friendly interface to the often complex models, while the analytical models are used to simulate our knowledge about events in the real world. But they are developed using complex programs as interfaces between data in existing models and data in WRIS, rather than over the basis of a common conceptual model.

The development of a conceptual model allows us to understand and simplify the problems from a specific domain. The choice of the model affects the flexibility and reusability of the resulting systems [8]. For a given architectural style, is possible to define a set of conceptual patterns that, designed to work inside the style, act as conceptual microarchitectures [16].

Analysis patterns (APs) are conceptual, because they represent the way we think about the business. They are defined to make the reuse of conceptual modeling solutions possible, using terms and jargons from the application domain [15]. Although APs have been widely used in other domains, including geographic applications [14], there is nowadays no consensus about conceptual models for hydroinformatic systems.

This paper presents an architectural style and conceptual microarchitectures that serve as the basis for WRIS systems design, trying to meet the exposed requirements. The research results will be applied in the development of an information system for the Tierra del Fuego Water Resource Department.

The paper is organized as follows. Section 2 explains the benefits of using analysis patterns for conceptual modeling. Section 3 presents a physic domain model for WRIS, which is used as the basic input for the analysis components identification. Section 4 presents the architectural style that allows understand and organize interrelations between simulations models and other environmental information systems, which interact with WRIS and to represent geographic information, by the means of a conceptual framework. In Section 4, examples of conceptual architectures for the specific domain based on APs, are given; they allow us to model in a flexible way, the complex process present in the living world. Finally Section 5 gives the paper conclusions.

2. CONCEPTUAL PATTERNS

Patterns have been used in software engineering to enable the reuse of successful solutions for recurrent problems in various steps of the software development process [2].

Actually, depending on what stage or abstraction level they are applied, pattern categories may be classified [2] as: architectural patterns [6], analysis or conceptual patterns [8], design patterns [10], idioms and process patterns.

The *term analysis (or conceptual) pattern* was introduced by Martin Fowler to describe solutions related to problems that arise during both the requirement analysis and the conceptual data modeling phases, whose form is described by means of terms and concepts from an application domain. Fowler gave the following definition*: "A pattern is an idea that has been useful in one practical context and will probably be useful in others"* [8]. APs reflect conceptual structures of business processes rather than actual software implementations.

An Analysis Pattern is a set of classes and associations that have some meaning in the context of an application; that is, an AP is a conceptual model of a part of an application [15].

They contribute to the software development process in two main tasks: speeding up the analysis abstract model that captures the main requirements of a concrete problem, providing reusable analysis models with examples and facilitating the transformation from the analysis to the design model.

Analysis patterns are application dependent; their semantic describe specific aspects of some application domain. They allow define a set of conceptual models that, together, describe a "domain language" [8].

In the present paper, the use of analysis patterns during the conceptual modelling stage, will help us to define a domain language for the domain problems related with WRIS systems.

3. OBJECT DOMAIN MODEL

The first stage in the development of conceptual models for WIRS is the identification of environmental data objects that hold the different processes related to WRIS.

Environmental objects can be grouped into a number of classes, that structures the environment into three media: ground, water and air. This simplified taxonomy is commonly used by government agencies. There are more sophisticated taxonomies, like the Günther [12] one, but for the purpose of the present work, and because of the domain features, the following classification is shown in Fig. 1:

Hydroecological Objects
HydroComp
Basin
Watershed
River
Channel
Acuifer
Lake
Reservoir
Depression storage
Glacier
Flood Plain
Soil (TE)
Vegetation (TE)
Acuatic species (AE)

Atmospheric Variables
ClimVar
Precipitation
Temperature
Humidity
Wind
Solar Radiation
Atmospheric Pressure
Snow

Hydrologic Variables
HydroVar
Flow
Water Level
Environmental parameter
Sediment

Human Activity Objects
UseComp: Astraction - Discharge - Effect
TecnoComp: Central, Treatment Plant, Perforation

Measurements Objects
Hydrometric Station
Control Section
Sensor
Measurement
Observation

Fig. 1. Taxonomy for WRIS Domain Objects

The physical domain model is presented [13] in Fig. 2, considering two different levels in the domain problem: water information level including the real world data objects and simulation level holding objects from the abstract world of models.
Corresponding to these problem levels, there will be two layers in a WRIS system: Information and Simulation layer.

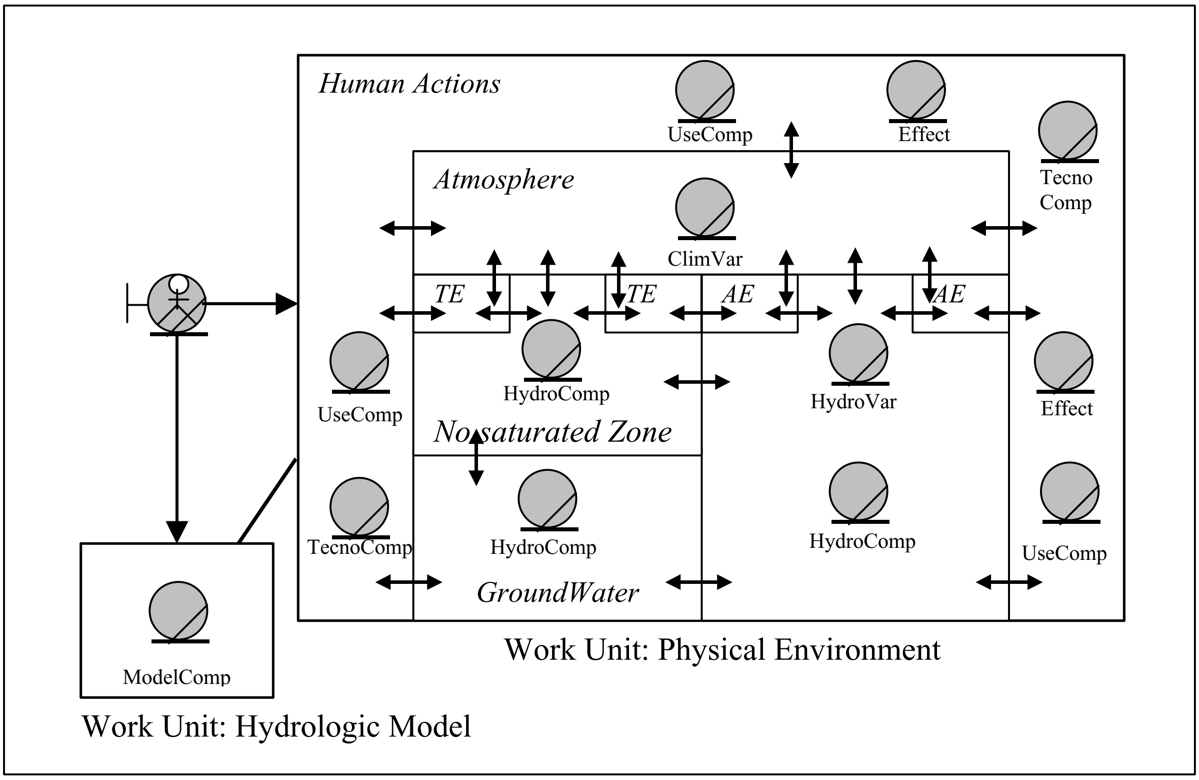

Fig. 2. WRIS Physical Domain Model- Adaptation from Blind et al [4]

4. ARCHITECTURAL STYLE FOR A WRIS

To face the problem of integration between models, WRIS and other environmental systems, as well as the geographic phenomena representation, it is important to define a general architecture [16] that simplifies understanding and organizing the development of complex systems.

Fig. 3 presents a conceptual architecture based in the architectural pattern Layers, which defines a way to organize the model in layers [6] reducing dependencies and helping us to identify what to reuse.

A system with layered architecture [13] has individual application subsystems at the top, built from subsystems in lower layers, such as frameworks and class libraries.

Application subsystems will be found in two top layers: application general and application specific layers. The application general layer is called: "Environmental Information Layer". This is the one where Water Resource Information is interconnected via interfaces with other environmental subsystems like: Soil, Climate, Vegetation, etc. The application specific layer: "Simulation Layer" includes subsystems referred to different simulation models that use the information resident in the Information Layer subsystems.
Lower Layers (middleware and system-software level) are general to several applications. In the middleware layer, it is presented a conceptual framework for SIG [15]. Subsystems in the application layers can reuse classes and relations in the framework for the hydrological components geographic representation.
The system-software layer is not shown in the diagram.

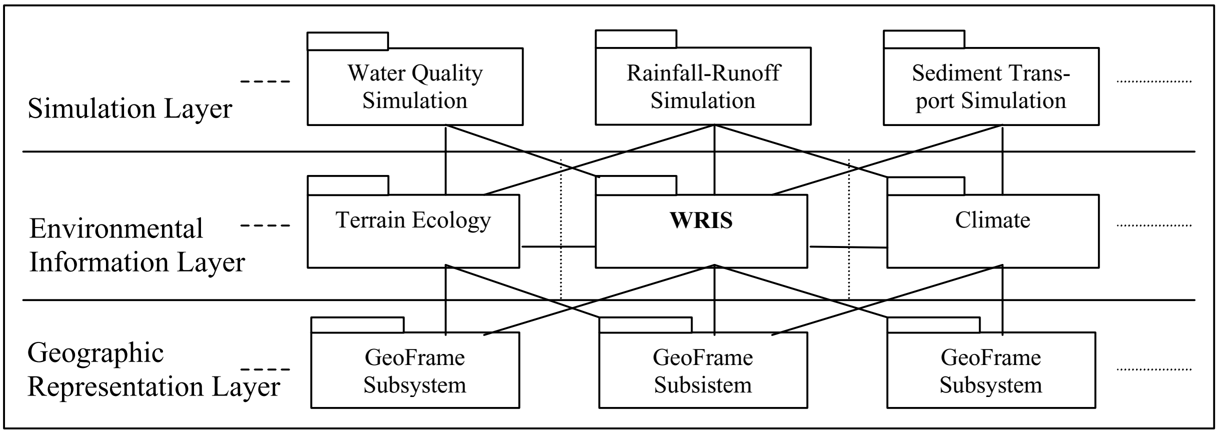

Fig. 3. WRIS Architectural Style

5. CONCEPTUAL MICROARCHITECTURES

Using the domain objects and the requirements exposed in Section 1 as inputs to the analysis process, it is possible to identify the main *types or interfaces* used for conceptual models. They are:
Hydroecological object HydroCom*p*: Basin, River, Channel, Lake, Reservoir.
Hydroecological variable HydroVa*r*: flow, volume, water level, quality Parameter
Measurement Objects: Sensor, Instrumental, Section Control, Station.
Measurement Variables: Measurement, Observation
Human activity Objects: Abstraction, Plant, Central, etc. Related with water use: Use, License, Effect

During this stage, the UML notation [5] is chosen for class diagrams specifications, with specific extensions for geographic models [15].

Geographic representation of hydrologic components

The problem of hydrologic variables and objects geographic representation is solved by means of the Object Oriented Conceptual Framework (GeoFrame) specialization. GeoFrame serves as a basis for class diagrams constructions to model geographic databases. Souza [17] defines a framework as being *"a generic design in a domain that can be adapted to specific applications, being useful as a mold for constructing applications"*.
Lisboa [15] developed a conceptual framework for geographic applications and defined stereotypes to express different relations in the framework, making the stage of mapping between the conceptual and logical design simpler.

There are four main classes in GeoFrame: GeographicRegion, Theme, NonGeographicObject, GeographicPhenomenon, which generalize in a high level of abstraction the elements of a geographic data scheme.

The framework specializes the GeographicPhenomenon class in Geographic Objects and Fields, decoupling their representation, allowing this way, different spatial representation for them.

Geographic Objects is represented by Spatial Object that may be of the following types: Point, Line, Polygon, Cell, ComplexObject. GeographicField is represented by FieldRepresentation, that may be of the following types: GridOfCells, AdjPolygons, Isolines, GridOfPoints, TIN.

Theme and GeographicRegion are fundamental classes for any geographic application. For each region is possible to define a collection of themes as: public transportation, buildings, etc. A theme defined during conceptual modeling can lead to the implementation of several layers in a GIS.

In this paper, GeoFrame is specialized for a WRIS, acting as the basis of the conceptual model in a middleware architecture layer, under the following considerations:

1) The themes of interest for each Geographic region will be: Water Resources, Soil, Land use, Climate, Terrain Ecology, that is to say, subsystems defined in the environmental information layer.
2) In any region where it's necessary to define an Environmental Information System, the different hydrologic components as well as the other environmental components, will belong to a *hydrographic basin*, which acts as the unit for natural resource planning and management [18]. See Fig. 4.

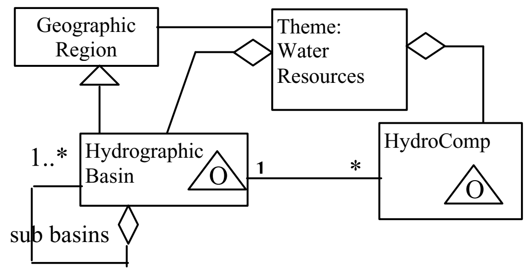

Fig 4. Geographic Region for a WRIS

The stereotypes shown in Fig. 5 help us to be sure that each component has its spatial representation defined in some system.

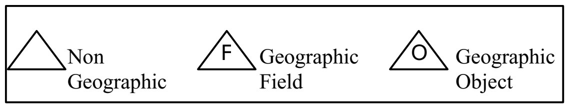

Fig 5. Stereotypes for generalization

WRIS Spacio-temporal Objects and measurements

What to measure and model: HydroComp

HydroComp may be of different types. To model the main hydrological components of a WRIS, the following hierarchy adapted form Alfredsen [1] is presented in Fig. 6.

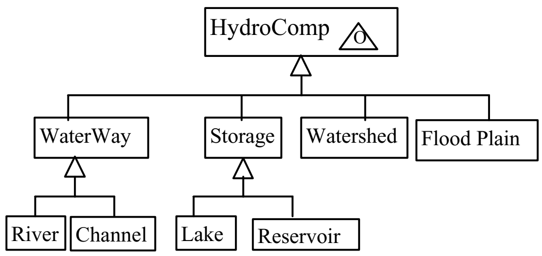

Fig. 6. Hydrologic components hierarchy

It is defined a common interface for all objects which share a common behavior: they hold a water volume and it's possible to compute a component output flow for them, by means of some function relating inputs with outputs.

Measurements

WRIS normally record information about measured hydrological variables (such as flow or water level), and water quality parameters. The conceptual model for measured variables is made decoupling the control section from the hydrological component as a separate geographic object and applying and adapting the *Measurement* pattern, developed by Fowler [8] for the Health domain. This pattern allows recording quantitative information. It is also combined with an *Environmental Quality Parameters*

pattern adaptation [14] developed for environmental systems, as it is shown in Fig. 7.
The advantage of using Measurement pattern is the following: Normally, quantities can be used as attributes of objects, but for large time-series, this is not a good approach, and it's necessary to treat measurements as objects. The pattern is also useful to keep information about individual measurements.

Units can be represented explicitly in the model, allowing this way to convert quantities from one unit to another.

It is also recorded the admissible range for each variable, with the purpose to don't get erroneous values into the series, applying Pattern Range.

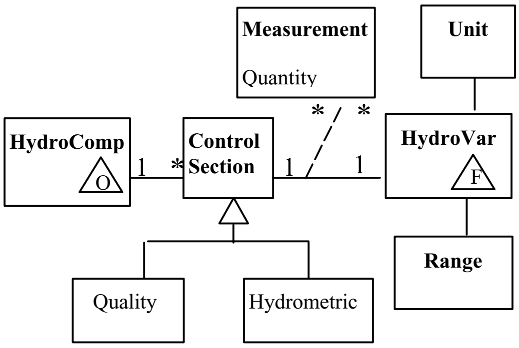

Fig 7. Measurements in a Control Section

As it's shown in the diagram, using extended UML notation allow us to easily define an appropriate representation for geographic objects and fields.

Calculated measurements

Some kind of hydrological variables such as river flow, can't be directly measured by the means of a sensor. There are some hydrometric methods than involve a series of steps and specific instrumental, to calculate the desired value from some initial measurements. An important knowledge concept to keep, is the method by which observations were made. The conceptual pattern Protocol [8] is applied to record the selected approach.
A Calculated Measurement protocol represents a calculation done on measurements already present in the domain. The result of a computation is treated as an object, and knows what computation caused it.
The calculated measurements protocols include the formula by which they are calculated. This is shown in Fig. 8.

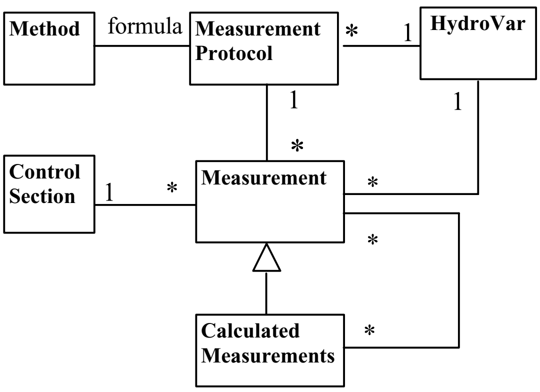

Fig 8. Calculated Flow Measurements

Measurements time recording

A key question related with measurements is the time when they were done. In this domain, it's usual to find variables with different measurement frequency, i.e. annual precipitation, daily runoff, hourly water level and so on.

Normally, time points come at various levels of precision and it's necessary to know it, so it's possible to answer questions such as the moment when some event occurs. Then, a flexible architecture must present time points in different level of precision, as it is shown in Fig. 9.

It is possible to apply the Time Point pattern [9]; it represents a point in the time for some granularity. Time Point decouples time from measurement, assigning precision and bringing as a basic service a method like "obtain actual time point".

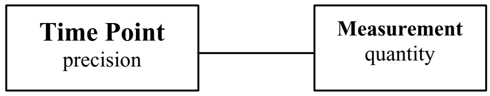

Fig 9. Measurement Time Recording

Control Section Temporal Properties

There are some temporal attributes in hydrologic objects, such as the instrumental used for measurements. This may be model as an attribute of Control Section. But this way, it´s possible to ask for this property *now*, and usually it will be necessary to know about the instrumental used in the past, for questions such as comparison, calibrations, etc.

It's possible to apply Time Property Pattern [9], which represents a property that changes over time. This pattern is useful when a class has some property that display temporal behavior, and it's necessary an easy access to those temporal values. See Fig. 10.

The key to this pattern is providing a regular and predictable interface for dealing with those properties of an object that change over time. The most important part of this lies in the accessing and updating functions that take a timepoint as an argument. This way, it's possible to ask questions like: "Which was the installed instrumental on May 19th, 1998?"

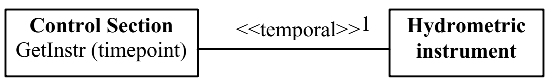

Fig 10. Temporal Instrumental in Control Sections

Observations

Sometimes besides the quantitative data, there is also some available qualitative information about hydrological phenomena that is wanted to be recorded. Then, it's possible to define a new type, Category Observation, which has a category instead of a quantity.

The Measurement and Observation Pattern [8], is applied using a new type Observation that acts as a supertype to a measurement and a qualitative observation. The new type HydroPhenomena defines possible values for some hydrological phenomena type. It is Shown in Fig. 11.

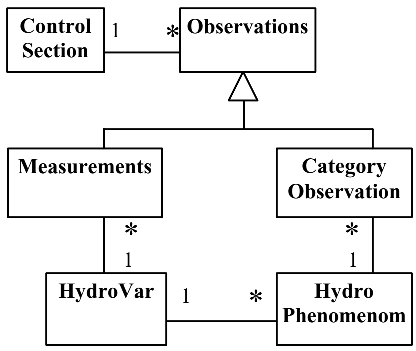

Fig 11. HydroPhenomena Observation

Observed Events

The use of hydrologic models for flood predictions implies the need of available information about *measured events* (unusual flows). Sometimes there are no measurements available for the event occurring time, but there is some other information of interest, given by residents about the flood beginning and ending time, marks in the land, etc. This information allows the flood hydrograph estimation.

Dual Time Record pattern may be adapted for these situations. This pattern allows both periods and single points to be recorded, because most events have a separate occurring and recording time. The pattern is adapted to this case, as it can be seen in Fig. 12, separately recording the hydrologic event observation and recording time and its period of occurrence

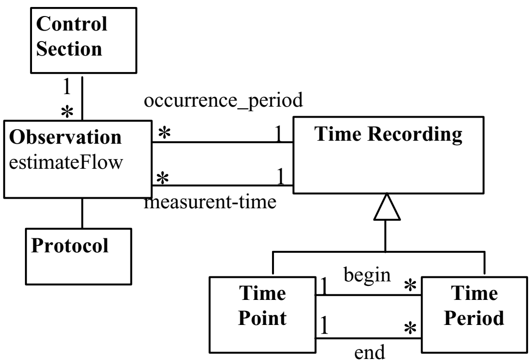

Fig 12. Observed Events recording

Environmental Associated observations

Many statements about environmental observations in water bodies are made using a process of "diagnosis", inferring environmental effects based on parameters observations. See Fig. 13.

For the recording of these environmental observed problems in water bodies, it is adapted the Associated Observation pattern [8]. This pattern can be used to record the evidence observations, plus the knowledge that was used for diagnosis. It presents two levels: the knowledge level describes what chains are possible, while actual evidence chains are recorded in the operational level.

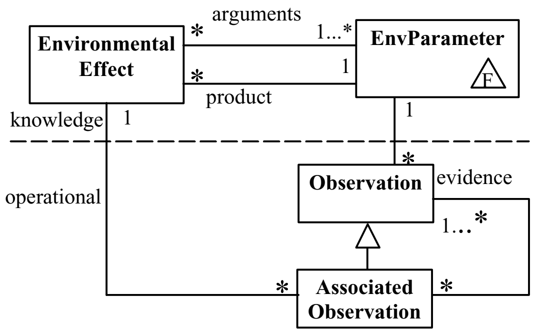

Fig 13. Environmental Effects Recording

Analysis Pattern for Integrated Hydrologic Simulation

It was stated the requirement of integration facilities for hydrologic simulation models to WRIS, allowing them to use the data resident in the information layer and the benefits from GIS. Considering that this is a recurrent domain problem, it is defined an analysis pattern for conceptual modeling of this requirement; it is shown in Fig. 14. The Context for this pattern is already exposed.

Name: WRIS-Hydrologic Simulation Integration

Problem: Developing an appropriate conceptual model for hydrologic simulation facilities in WRIS.

Forces:

- Hydrologic simulations models usually utilize environmental data resident in WRIS, but they are developed in an isolated way.
- It is possible to simulate different specific behaviors for each HydroComp, but it is not desired to overload classes in the Information system with specific simulation scenarios behavior.
- Each hydrologic model may present different configurations, depending on the methods and parameters selected for a specific scenario.

Solution:

- Having in mind the architecture style defined before, there are two different conceptual application layers defined: the Information layer includes hydrologic components identified in the physical domain mapped to WRIS, their related measurements and observations. In the Simulation layer, there are simulation scenarios structural components and the knowledge about different models (methods, parameters, etc.)
- It is defined a structural component in the SL called *ModelComp*, which adds specific model behavior to WRIS components.
- There are two levels defined inside the Simulation Layer: knowledge and operational levels [8]. The knowledge level includes a group of objects that describe how another group of objects should behave. There are several simulation strategies and associated parameters for each type of model defined inside it. This allows a flexible configuration for simulation scenarios.

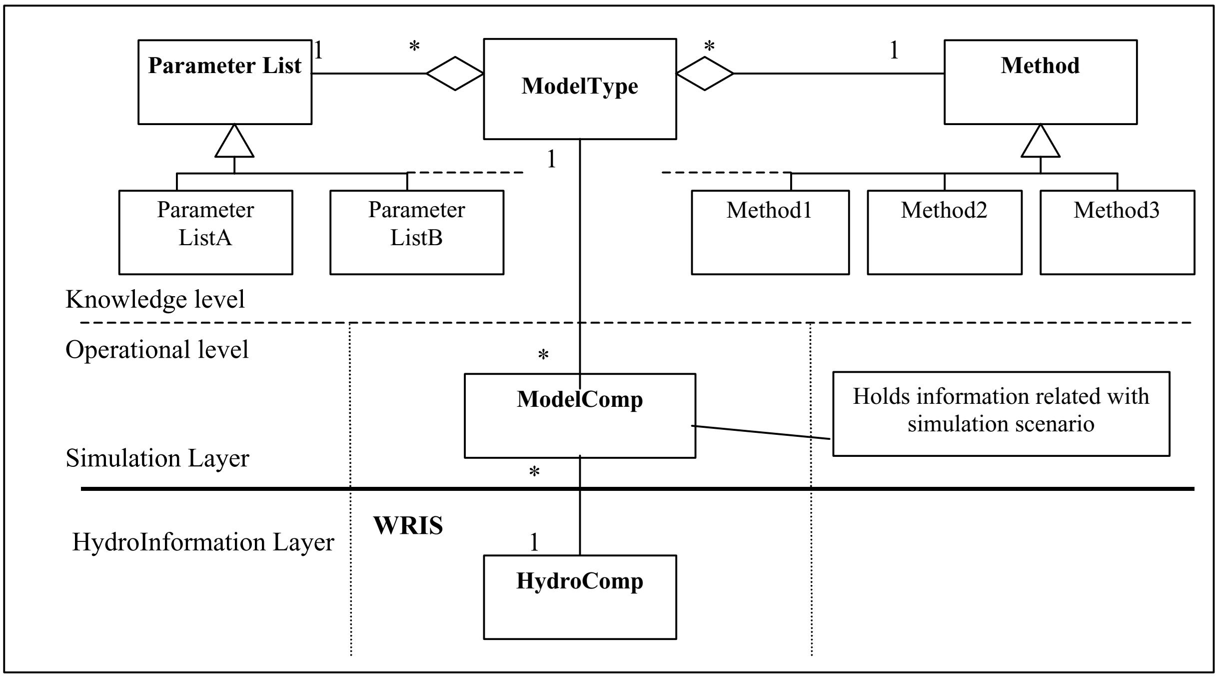

Fig 14. Conceptual pattern for WRIS-Hydrologic Simulation Integration

6. CONCLUSIONS

This paper demonstrates the convenience of using different software mechanisms for flexible conceptual modelling in a specific domain, whose main feature is data complexity.

The defined Object model for the physic domain serve as the basis for analysis classes identification through different applications. The exposed layered architecture allows concentrating in the development of conceptual models for the application specific layers, leaving to middleware layer the solving of geographic representation problem. Using conceptual patterns for a WRIS facilitates the appropriate representation of spacio-temporal hydrological phenomena and allows a flexible choice and configuration of different types of models and simulation scenarios.

7. REFERENCES

[1] Alfredsen J., *An object oriented framework for application development and integration in hydroinformatics*. Dr. Eng. Thesis, Norwegian University of Science and Technology, 1998

[2] Appleton B., *Patterns and Software: Essential Concepts and Terminology.* Página Web: www.enteract.com/~bradapp/, 2000

[3] Beven K., *Rainfall-Runoff Modelling*. Wiley, 2000

[4] Blind M., Adrichem B., *Generic Framework Water: An open modelling system for efficient model linking in integrated water management - current status* Paper presented at the 4th International Eurosim 2001 congress "Shaping Future with Simulation".

[5] Booch G., Jacobson I., Rumbaugh J., *The Unified Modeling Language* Addison-Wesley Publications, 1998

[6] Buschmann, F.; Meunier, R.; Rohnert, H.; Sommerlad, P. and Stal, M., *Pattern-Oriented Software Architecture: A system of patterns*. New York: John Wiley & Sons, 1996.

[7] Fedra K., *Integrated Environmental Information Systems: from data to information*. In: N.B. Harmancioglu, M.N. Alpaslan, S.D.Ozkul, and V.P. Singh [eds.]: Integrated Approach to Environmental Data Management Systems, 367-378. Kluwer, Dordrecht., 1997

[8] Fowler, M., *Analysis patterns: reusable object models*. Menlo Park: Addison Wesley Longman, 1997

[9] Fowler M., *Patterns for things that change with time.* Fowler Web Page, 2001

[10] Gamma E. H., D*esign Patterns. Elements of Reusable OO Software* Addison-Wesley, 1997

[11] Gordillo S. Tesis de Magister en Ingeniería de Software, UNLP. *Modelización de campos continuos en Sistemas de Información Geográfica*, 1998

[12] Günther O., *Environmental Information Systems*. Springer-Verlag, Berlín, Germany, 1998

[13] Jacobson I., Booch G., Rumbaugh J. *The Unified Software Development Process* Addison-Wesley Publications, 1999

[14] Lisboa J., Iochpe C., Beard K., *Applying Analysis Patterns in the GIS Domain* Presented at the 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, November 1998.

[15] Lisboa J., Iochpe C *Specifying Analysis Patterns for Geographic Databases on the basis of a conceptual framework.*, 2000

[16] Monroe R., Kompanek D., Melton R. and Garlan D. *Stylized Architecture, Design Patterns, and Objects*, 1996

[17] Souza C. *A framework for cooperating diagrams editor based in anotation*. Unicamp 1998. Master Thesis.

[18] Urciuolo A., Iturraspe R. *Microarquitecturas de Diseño OO para Modelos hidrológicos.* Jornadas Universitarias de Informática, Congreso del Nuevo Cuyo, Octubre de 2001, San Juan.