Structuring the Domain Knowledge for Model-based Decision Support to Water Management in a Peri-urban Region in India

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Abstract

The paper presents first results in designing and realizing a computer tool that is meant to support decision making in the context of peri-urban development with a focus on issues of water management. This is associated with research on the development in the Sriperumbudur region near Chennai that is conducted by the Indo-German Center for Sustainability at IIT Madras. We describe and illustrate the chosen approach, which is based on establishing a library of models of the relevant physical, technical, social, economic, and governance processes relevant to the problem domain and then using it for both predictive and explanatory tasks.

Introduction

Planning and decision making in urban and peri-urban development are facing significant challenges of different origin:

- They have to reflect complex interactions among a variety of factors, including natural aspects such as topographic, hydrological, climatic, and ecological ones, as well as social, economic, technological, and administrative impacts: migration, housing, water and energy supply, waste management, traffic, etc.
- Turning plans and decisions into reality often involves a large number of stakeholders with particular interests such as law-makers, administrative units, expert committees, lobbyists, migrant labor, real estate sector, and others.
- While several of the aspects are general and shared by different regions, there will always be significant differences, e.g. regarding specific natural, cultural, administrative, political, and economic conditions, which prohibits the development of universally applicable rules and patterns, but requires region-specific analyses and decisions.

Computer aid to conducting the necessary research and for decision making is desirable, but as of now limited to acquisition and storage of data (aerial and satellite data, geographical information systems, GIS) and to modeling and simulation systems (e.g. hydrological models) that have to be handcrafted and adapted to local conditions. Producing decision support systems for each region and problem would be costly if feasible at all.

In order to reflect these challenges, we propose a knowledge-based-systems approach, more precisely model-based decision support systems:

- i.e. systems capturing the knowledge about all known (or hypothesized) potentially relevant interdependencies and the decision processes and governance structures, stakeholders, their roles and guiding principles in models, i.e. a computer-based representation that can be used to support, for example, interpretations of observations, prediction of future evolution, and planning of interventions.
- This knowledge base has to be structured as a collection of elementary, independent model elements that can be combined to form models tailored to different individual scenarios for different regions, contextual conditions, or hypotheses. This also allows for an easy modification of individual model fragments and an extension of the entire model library.
- Based on this, computer tools can be developed that support both researchers and decision makers in their work. This could happen to evaluate and suggest certain policies of government and administrational institutions, but also to private companies, which, for instance, are obliged to invest in improvements if they are located close to water bodies.
- Such tools should be utilizable without requiring that users have detailed knowledge about the content, the kind of representation, and technical aspects of the models and the algorithms that exploit them.

This paper presents the first results of an analysis laying the foundations of a planned project along these lines which focuses on water management in the Sriperumbudur region near Chennai, India. It is linked to ongoing studies at the Indo-German Center for Sustainability (IGCS) at the Indian Institute of Technology Madras (IITM), Chennai, on problems of water, land use, energy and waste in the area.

The following section discusses peri-urban development in the Sriperumbudur region. Section 3 outlines the foundations of model-based decision support. Then, an approach to systematize and structure the model library is presented, and we introduce some sample models for the library.

Peri-urban Development in Sriperumbudur

The Area

Until quite recently, much of the research on climate change adaptation has focused either on cities and their adaptive capacity (service infrastructure, disaster preparedness, vulnerable groups) or on rural areas identified as specifically vulnerable to droughts or floods. Peri-urban areas bring up new issues that move across disciplinary but also governance and institutional boundaries, and as such define a complex and highly dynamic environment in their own right. The peri-urban, which can be treated as a transitional zone between the urban and rural of rapid changes, is now being recognized as an entirely separate socio-spatial configuration with distinct challenges of sustainability [Adell 99], [Simon 08].

In India, peri-urban areas are typically the sites of fastest growth outside the area of metropolitan corporations and the so-called Tier-II cities [Vishwanath 13]. In the face of climate change, it has become imperative to assess and steer the development process in these regions in order to ensure their sustainability and resilience. Though still relatively low, the level of urbanization in India has experienced a very rapid ever-increasing urban growth over the recent years.

As one of the six most urbanized states (with an urban population much higher than the national average of 31.1%), the state of Tamil Nadu is undergoing rapid urbanization. The City of Chennai (the former Madras) of The Greater Chennai Corporation metropolitan region is the most important location of the Indian and foreign automobile industry. Since Ford Motor Co., Hyundai Motor Co., Nissan Motor Co., Renault SA, Daimler AG and BMW AG are based in the Chennai region, some call it the 'Detroit of India' (The Wall Street Journal 2010).

Because of its geographically confining location in the northernmost part of Tamil Nadu, close to the border of Tamil Nadu's neighboring state Andhra Pradesh and the Bay of Bengal, the traditional industries in Chennai evolved mostly around the port and the vicinity of formerly abundant water resources in the northern outskirts of the old city, where industrialization reached stagnation due to unavailability of land. State driven modern industrialization started relatively late, after the occurrence of land reclassifications of the nature of waste land to industrial parks (including SEZs, i.e. special economic zones) or farm land to residential areas, which paved the way for the growth of industrial estates outside the city and triggered the evolution of a suburban/peri-urban region, which today may be seen as a positive situation.

The selected peri-urban study area of the IGCS project (see [Adelina et al. 15]) has been initially defined by administrative boundaries, constituting one of the ten taluks (the administrative divisions below the district) in Kancheepuram district of Tamil Nadu West of Chennai, which covers 371.94 sq.kms (of 4432 sq.kms of the district) and contains a population of 316,918 persons as per 2011 census (8% of the district). Within this district, Sriperumbudur Town Panchayat (i.e. the smallest unit of local administration) has been transformed from a village into an industrial hub in the past 20 years.

Since the peri-urban is characterized by the absence of clear boundaries, the region as a spatial unit is flexibly applied to the context of analysis and action. For instance, in relation to the water basin or the institutional setting and planning areas there are multiple overlaps, interfaces and levels which define peri-urban Sriperumbudur in various ways beyond the taluk boundaries.

In order to cope with the rapid urban growth, the boundaries of the Greater Chennai Corporation were gradually expanded in 2011. The process can be considered in two ways; as an attempt to formally integrate peri-urban areas with the metropolitan region or as swallowing of formerly independent areas to secure or satisfy natural resources needs for the city.

Impact on Water Management

Urbanization and industrialization change land use and use of water resources in a structural, qualitative, quantitative, and also in a political way. The impact on water and land resources has a number of different consequences:

- An increase of the consumption of water for domestic or industrial purposes due to piped network requirements and different consumer behavors (Minimum basic water need in Indian cities is 120 l per capita day and in rural areas 55 l per capita day) combined with an increase in waste water generation.
- A reduction of the available water resource quantities (lowering the ground water table, reducing reservoir capacities, eliminating traditional means of water storage and water harvesting).
- For coastal areas, salt water intrusion due to excessive groundwater abstraction.
- Generation of solid waste which accumulates in lower laying areas, usually water-logged areas or traditional water storages.
- A change in the kind of waste water (volumes and physico-chemical composition).

• A deterioration of the quality of resources for drinking water (ground water, surface water) due to absence or only partial treatment of waste water and absence of sanitary landfills.
• Increased amounts of storm water due to increased direct run-off of rain water due to lack of detentio/ retention areas and sealed surfaces.
• Reduced rainfall over urbanized areas due to heat island effect and changed albedo. Increased temperature in urbanized areas due to reduced moisture availability / reduced evaporation because soils are sealed and open water bodies are covered in solid waste or dried up.
• destruction of systems of interconnected water reservoirs and, thus, the ability to avoid or mitigate flooding, to store water for irrigation and drinking, or to allow the percolation of water to recharge aquifers.

In peri-urban development in the Sriperumbudur area, specific aspects add to this:
• Loss of traditional powers and knowledge to manage established rainwater collection and cascading water supply and storage systems [John 15].
• change in purpose which leads to the interruption of water infrastructure systems made for agricultural irrigation and used now for urban water supply with tankers. Continuous subsidies for the abstraction of groundwater by farmers (unlimited free-of-charge power consumption for pumping) creating a flourishing water market (former farmers sell water to newcomers in the peri-urban areas) and to city water supply.
• Upgrading or value-addition of former wetlands and man-made lakes to some other public infrastructure such as highways, sports stadiums, railway stations thus destroying traditional localized means for water supply from ponds and rain water harvesting.

Climate change, with its impact on the temporal distribution and amount of precipitation is projected to increase the number of extreme rainfall events per year and at the same time reduce the number of rainy days per year in Tamil Nadu [Chaturvedi et al. 10].

Model-based Decision Support

The Foundation

In our approach, we follow Qualitative Process Theory ([Forbus 84]) and our logical and computational reconstruction of it ([Heller 2001], [Heller-Struss 02], [Struss 11]). A process states that certain effects will be established whenever its preconditions are satisfied, i.e. an implication:

$$\text{StructuralConditions} \wedge \text{QuantityConditions} \Rightarrow \text{StructuralEffects} \wedge \text{QuantityEffects},$$

where StructuralConditions and StructuralEffects assign existence to objects and structural relations, and QuantityConditions and QuantityEffects contain assignments of values (or ranges) to quantities. In addition, QuantityEffects include also **influences**, which capture the contribution to the process to the dynamics of the systems (which may rival with counteracting influences of other processes). We assume that there exists a **process library** representing the core of the domain knowledge.

Constructing situations involves starting from the given observations (which may be considered as facts or default assumptions) and iteratively completing them in two directions:
• Forward completion: adding all implications of an intermediate result of the construction process and the process library, i.e. instantiating processes whose preconditions are satisfied and their effects. This establishes the causal impact of the intermediate result, but it does not address the main goal, namely finding a reason for what has been observed.
• Consistency check: if the resulting situation is consistent, it is possible answer to situation assessment. Otherwise, it is incomplete causally upstream and requires
• Backward completion: this looks for process candidates whose effects yield changes in quantities and/or existence of objects and relations that are unexplained. If there is no such process, the search is cut off here. Since there can be several candidates, the search may branch.

The somewhat surprising fact that pure consistency-based reasoning yields an abductive result is due to two axioms:
• **Influence resolution**: if its result yields an inconsistency, it can only be resolved by an additional process; a special case is a change in a quantity that is not influenced in the current model .
• **Existence default**: objects and relations do not exist unless they are given as observations, effects of active processes, or as introducibles, which are discussed below.

These closures are supported by closed-world assumptions that are associated with existence variables and quantities. In the Generalized Diagnosis Engine G+DE ([Heller 01], [Heller-Struss 02]) consistency-based diagnosis ([de Kleer-Williams 87], [Struss 08]) is performed to deliver (minimal) sets of assumptions that create an inconsistency. Resolving such an inconsistency may involve simply dropping some inappropriate default assumptions, while revising a closed-world assumption means searching for additional processes that provide an effect on the respective variable and, hence, performing backward completion in an informed and focused way.

The concept of **introducibles** is crucial for terminating the search: otherwise, repeated backward completion would usually ultimately result in an inconsistency, because some object remains unexplained. This reflects that each model library has a limited horizon of what can be explained. For instance, in the context of our project, we may require the system to discover the origin of a high arsenic concentration in drinking water (e.g. minerals containing arsenic in certain rock layers in the ground that are touched by wells), but not an explanation in terms of geological processes that created those minerals). All objects that do not occur in a StructuralEffect of any process in the library have to be marked as introducible. However, for a particular task, the model boundary, i.e. the scope of the explanation, may be tighter.

As a result, situation assessment, starting from initial assertions, includes causally downstream processes and their impact, but also causally upstream processes and their impact. Since backward search will commonly detect several potential explanations, it will usually deliver alternative results, and the user may have to pick the most plausible one.

Characterized in a more formal way, the **result of situation assessment** should be a **minimal** situation
• containing **all facts**
• otherwise only **introducibles** and
• **effects** of occurring processes
• being **closed** w.r.t. **effects**,
• in which **a maximal set of assumptions** holds.

Challenges of Water Management Addressed

The various issues mentioned in section 2 interact closely. These complex interdependencies make both the task of assessing the impact of previous or planned steps in peri-urban development on water and the development of adequate policies and the planning of specific interventions and constructions difficult.

In addition, any establishment of regulations and the realization of any constructive activities have to reflect the (formal and informal) governance structures, i.e. the interest, role, and competence of various stakeholders (central and local administrative institutions, communities, companies etc.).

These governance structures are complex and specific to a particular country, state and area (e.g. there is an overlap of responsibilities of the city of Chennai and the Sriperumbudur taluk, because of the delineated jurisdiction of the Chennai Metropolitan Development Authority CMDA).

Analysis and proposal of useful interventions combine qualitative and quantitative aspects. While, on the one hand, constructive actions need a numerical specification (e.g. regarding the diameter of pipes or throughput through a treatment plant), on the other hand, scenarios to be analyzed will often be characterized in qualitative or symbolic terms (“monsoon rainfall”, “Toxic waste water”), and information about real situations tends to be approximate and

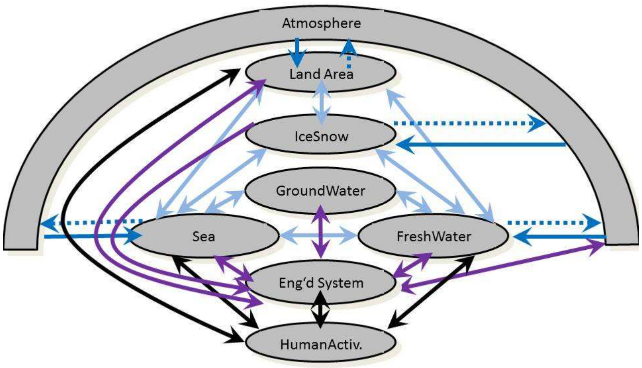

Figure 1 High-level Domain Concepts

stating tendencies (amount of required water supply”, “reduction of agricultural land use”).

Structuring the Model Library

In our application domain, the model library has to comprise model fragments that represent a fairly large number of interdependencies with a high diversity:
• Basic **physical processes**, such as downhill flow of water, salinization of ground water, and evaporation
• **Chemical and biological processes** like reactions due to pollution, its impact on living organisms, or algal bloom
• Various kinds of **human activities**: transporting and polluting water, constructing dams and dwellings, etc.
• **Economic developments** (changes in cost of land and accommodation, financial investments)
• **Political and legal regulations** and processes such as: administrative procedure, lobbying activities, formal and informal decision processes, water allocation priorities, water allocation tools, bulk water provisions, and water use charges (use and pollution) .
• The impacts of different kinds of **land use** (agriculture/horticulture, grazing, mining, …)
and many more. Filling such a diverse library is a genuine challenge and will not succeed without initial work on categorizing and decomposing the relevant body of knowledge and, based on this, systematizing and structuring the model library in an appropriate way.

In this section, we discuss the results of a first analysis. The high-level structure is illustrated in Fig. 1. The top-level distinction is between the interdependencies that are not controlled by humans but by natural “laws”, and human activities, artifacts and interactions among themselves and the natural objects (the bottom part of Fig. 1). We discuss these two “hemispheres” in the following two subsections.

The Physical Hemisphere

A central class of objects comprises land areas, more precisely: their surfaces that are usually not covered by water and possibly exploited by human activities, e.g. in agriculture, industrial production, or dwelling. Such land areas will be categorized by different land uses. They are further characterized by attributes, in our context (with a focus on water-related issues) by topographic information, such as altitude and slope (influencing flow of surface water), type of vegetation (affecting transpiration and water run-off), geological features (determining run-off, infiltration, aquifer formation).

Five classes are representing areas of water flow and storage:

• **Fresh water** bodies on the surface (lakes, streams, wetlands)
• **Groundwater**,
• **Oceans**, storing and moving salt water
• **Ice/snow** and glaciers, and
• **Atmosphere**

The latter will be the entry point for impacts of climate change, which becomes an essential factor in analyzing and planning sustainable development, e.g. through the amount and distribution of moisture, cloud coverage and permeability for sunlight, or heat exchange. From the perspective of water management, it directly interacts (in both directions) with land areas and the water bodies except for ground water, thus defining different basic processes in the model library: The solid dark blue arrows in Fig. 1 represent precipitation (snowing, frost, rain, dew), while the dotted dark blue arrows indicate transportation of water back to the atmosphere by evaporation (from water bodies and temporary surface water in land areas), transpiration (by vegetation on land areas), and sublimation (of solid water).

Already at this level of abstraction, it is evident that for different areas and/or different climatic conditions, the relevance of different elements of the model changes or vanishes. Decision support on water management in Sriperumbudur can safely ignore snow and glaciers, as well as direct influence by ocean water, while in Ladakh, snow and glaciers are essential, and in Chennai, salt water from the ocean infiltrates ground water. Other basic processes will occur in each model, which emphasizes the idea of configuring models from reusable model elements.

Like land areas, water bodies (except for groundwater) may need an association with different economic uses, such as fishing areas and fish farms or recreation (water sports, skiing) and, hence, linked to the concepts in the next subsection.

As a challenge to modeling, the spatial extension of the instances of the classes is not static: land, oceans, and surface water bodies may be seasonally covered by ice and snow, glaciers shrink, and land areas may be flooded.

Land areas and water bodies potentially exchange water among themselves, as indicated by the light blue arrows in Fig. 1. Besides the exchange between fresh water and the ocean (usually in one direction, unless affected by tides or storms), water from fresh water bodies or the ocean may inundate land areas and, in turn, runs off from land areas and melting snow and ice to the water bodies. Through infiltration, ground water is fed by fresh water, but also by oceans, if the water table is low, and discharges back into them. A high water table or an artesian aquifer may also generate flooding of land, unless the model opts for treating the result as a (temporary) fresh water body.

Actually, the arrows in the diagram discussed, so far, more or less correspond to the basic processes to be represented without requiring much refinement, and those ones that represent water flow are simply governed by gravity, i.e. directed towards the area with a lower elevation. This is what is mainly covered by numerical hydrological models.

From the perspective of management of drinking and waste water, not only the amount of moved or stored water is relevant, but also what is transported and captured in the water, such as salt, pathogens, toxic substances, and organic material. The distribution and transportation of such elements and possibly their transformation has to be captured by model fragments, as well.

What has been discussed, so far, captures basic natural processes of hydrological, biological etc. systems, chemical reactions etc. (although they may be triggered or influenced by humans (for instance, through water pollution). While this is a necessary ingredient to model-based decision support in the domain, water management has to consider human activities and, even stronger, is targeted at human interventions that, in interaction with the natural processes, achieve the fulfillment of certain goals. Therefore, we need to include a realm of human-related, social, administrative processes in the model library, which have to have a clear interface with respect to the natural processes.

The Human Hemisphere

Human interference with the processes described above often happens through constructed systems. They are very diverse and comprise water reservoirs for drinking water, wells, dams and water gates to prevent or control flooding, pumping and irrigation systems for agriculture, water treatment and desalinization plants, cisterns, urban retention/detention areas (on roof tops), . The level of scale and granularity of the model may vary: transfer of water may be related to individual water reservoirs or between different catchments. Even international trade with bottled water may be included as a mechanism for drinking water supply. We summarize this in Fig. 1 as a class of **engineered systems**. They **interact** (shown by purple arrows in Fig. 1) with

• **Ground water** (wells for extraction of ground water and injection wells for recharging it)

• **Freshwater** (canals and water gates for controlling flow and storage, extraction for drinking water treatment and disposal of water from waste water treatment or cooling systems of power plants, etc.)

• **Sea water** (dikes, desalinization plants, industrial run-off)

• **Ice and snow** (perhaps mainly one-directional: for instance, ice blocking water ways or the operation of facilities)

• **Land areas** (irrigation and draining systems, water distribution systems for industrial and domestic use)

• The **atmosphere** (systems for rain water harvesting, evaporation from stored water)

Finally, there is the most diverse field: **human activities**. They are linked to the above entities and processes (black arrows in Fig. 1)

• With **water bodies indirectly** through construction, operation, and use of the engineered systems discussed above (or suffering from their malfunction); ground water is exclusively accessible through them and

• **directly** by dumping waste water into sea water and fresh water, using water bodies for transportation, recreation, and economic exploitation (fishing and fish farms, salt production)

• With **land areas** by involvement in different land uses and their modifications (farming, grazing, acquiring or selling land, constructing "unauthorized colonies" (slums, gated communities that is))

• With the **atmosphere** by polluting it (and in turn suffering from it), modifying local climate conditions, e.g. increased temperatures in cities)

As we stated before, including **governance structures** in the model is essential for effective decision support, because the mere proposal of attempts to impose certain changes in the physical system is unlikely to be brought to a realization.

A more detailed and extended view on the lower part is depicted in Fig. 2. We introduce activities for

• **Building** the **engineered systems** (dams, pipelines, treatment plants, …) and for

• **Operating** them (distribution of drinking water, opening water gates, etc.).

Indeed, many decisions to be taken related to water management will aim at such interventions. In the modeling formalism, the first kind of process has the effect of bringing new objects into existence, while the second one changes states of such objects. In our application domain, the latter may trigger natural processes: for instance, open-

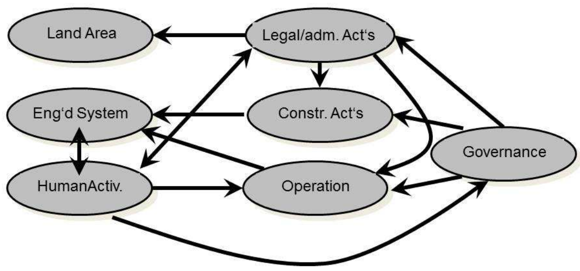

Figure 2 Human Activities and Governance Procedures

ing a water gate, say, separating a lake from a riverbed, results in a modification of the relative order of water levels in the lake, the water gate, and the river bed and will trigger a flow from one water body to the other one via the water gate. In a treatment plant, opening a certain valve may result in a flow of an oxidant into a water tank, which is a precondition for process of oxidizing dissolved iron contained in the water.

As a third type of activities in this context, we consider

• **Administration**, legislation, and financial acts, such as imposing limits on water consumption, controlling or subsidizing certain kinds of land use, changing ownership of land areas, providing compensation for damage or income loss.

Except for direct effects on land ownership, such activities will usually influence the physical world only via other human activities, social, economic, etc. ones or by setting the context for building or operation processes. For instance, financial incentives for growing certain crops influence decisions of farmers, which modifies consumption of irrigation water, hence the amount of water stored in reservoirs, etc. An impact on human behavior could also be exerted by information distribution, educational campaigns etc., and one might include them in the above class or create an additional one.

Finally, we need to explicitly describe

• **governance** structures and rules.

While the issue will occur in one way or another in other parts of the world, in the Sriperumbudur case, as in India in general, there are extremely complex structures. There are easily half a dozen institutions, legal bodies, advisory boards etc. at different levels (community, district, state, federal) involved in a single decision. Collecting and representing information about the various stakeholders, their role and interests, is an important part of the ongoing project at IGCS. A crucial issue is that many stakeholders may not operate in a coordinated manner; and, in addition, decision are also made 'off-the-rule-book'. i.e. by informal power plays.

In the decision support system we are aiming at, these governance procedures will need to be included as preconditions for certain interventions, i.e. it should not only recommend building a canal that connects two reservoirs, but

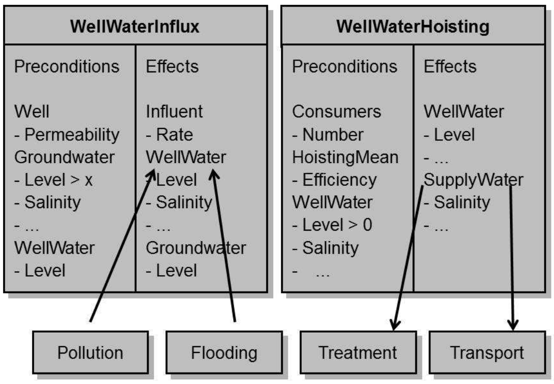

Figure 3 Engineered System "Well" and Human Activity

also which bodies will have to be involved in which role in order to plan, decide upon, finance, and construct it.

The governance models are **not** expected to actually **predict** the outcome of the respective planning or decision steps based on a detailed representation of the criteria, legal restrictions etc. The goal is rather enabling the system to **infer the preconditions** for the realization of certain proposed interventions. From the technical perspective, this means including their prerequisites in the backward completion of the model, thus determining, for instance, that the approval of a certain state government board is required for building a canal (but not predicting whether it will actually be approved). Furthermore, dependent on the location of the canal, certain local administrative bodies have to be involved in the planning, and the resulting plan needs financial contributions from the state government, the district, and, perhaps, companies in the area.

In order to achieve this, we need to represent the various institutions and legal entities that participate in certain procedures, the role they fulfill (officially or unofficially), preconditions for their activity etc. Such roles could be categorized as "planning", "deciding", "approval", "advisory" etc.

Sample Processes

We illustrate what has been introduced above using the example of a well. We reduce the process descriptions to the essential aspects, omitting, in particular, the detailed constraints and influences among the various quantities. The process WellWaterInflux (Fig. 3) is an instance of the interaction between an engineered system (the well) and a natural water body (groundwater) and follows straightforward physical principles. WellWaterHoisting (Fig. 3) captures the human activity related to the engineered system, namely extracting water from the well (which may then be subject to a treatment or transportation process). The figure also indicates how some other processes, such as pollution or flooding may affect the well water.

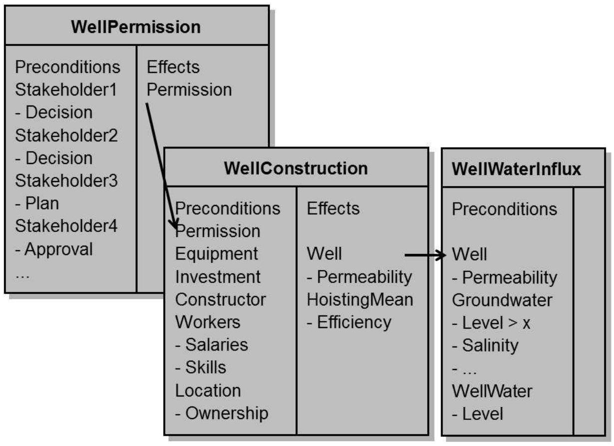

Figure 4 Constructing a Well requires a Permission

Fig. 4 shows that the well comes into existence through a construction process (see Figure 2). The precondition "permission" is subject to a respective process as part of the governance model that lists the stakeholders and their roles (Fig. 4). This can be further related to more detailed activities if needed and possible.

Discussion

We developed foundations for applying a generic approach to model-based decision support to the domain of peri-urban development with a focus on water management. Since the enterprise of building an appropriate model library has to be done in a distributed way by several (groups of) experts, it is essential to develop a systematic approach and a common ontology for integrating the various sections of the model library. Based on our current analysis, we can identify certain challenges and draw some preliminary conclusions.

• **Uniform Representation and Reasoning**: The analysis above suggests that we can actually use a single modeling formalism that allows integration of processes of quite diverse scope: natural physical phenomena, building and running man-made plants that interact with the natural environment, legal and administrative procedures that are relevant to proper planning of interventions etc.

• **Qualitative vs. quantitative** representation and reasoning: most of the interdependencies that have to be considered are of qualitative nature and lack precise numerical parametrization, which makes qualitative modeling and reasoning appropriate. However, some interventions need to be specified by numbers (e.g. determining the size and depth of a well, the required capacity of a water reservoir, the amount of water to be released through a water gate). This will require links to a numerical level, for instance, more precise hydrological models, calculations of water demand and supply etc. Also certain thresholds may have to be represented, esp. when effects are accumulated: the impact of a single well on the ground water table may be negligible, but too many of them located in a region may cause a significant reduction.

• Qualitative **spatial representation**: we expect that representing various land use areas and natural water bodies as compartments with certain topological relations (rather than detailed and quantified geometric features) in 2D will mainly suffice. Obvious exceptions are groundwater and ice or snow covering ground. This representation has to be linked to an existing geographical information system (GIS), which captures detailed information about the Sriperumbudur district.

• Multi-level **temporal representation:** A problem to be solved is the co-existence of processes that have some intrinsic natural temporal units at quite different levels. This may include daily peak periods of water demand, weekday-weekend patterns, monthly variations in requirements on agricultural irrigation, seasonal weather patterns over the year, long-term trends in changes in land use, climate etc.

• **Non-determinism**: many processes in this domain, especially related to human activities, but also with regard to biological and ecological systems and weather, cannot be described comprehensively as a causal interdependency, because there will be a large set of influencing factors that will be impossible to be included in the model. This applies, in particular, to the governance procedures that we want to include. Whether a certain decision will be taken or not, may depend on personal preferences, the date of the next elections, corruption, power relationships, etc. As discussed with respect to governance processes, this is not a fatal problem in the abductive direction, i.e. when generating possible explanations or establishing prerequisites. But the predictive power of the model suffers. Rather than following the common suggestion of using probabilities (which are not available, at least not comprehensively, and which make everything "somewhat likely"), a solution within the proposed system is the introduction of "unknown preconditions", whose fulfillment cannot be predicted by the model, but which can be subject to assumptions and explored in their consequences.

• Representing **intentions** and goals of stakeholders and human activities is a related issue. In reality, they have a crucial impact on triggering certain processes; but it is hard to impossible to derive them as a result of other processes.

The next step in the project will be consolidating and refining the conceptual structure and ontology by considering sample scenarios and building sections of the knowledge-base. We will need to focus on a feasible scope within the water domain. But we need to be open to later including links into the closely interacting aspect of energy, health, and waste, which are also studied at IGCS.

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