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Collaborative Modeling to Support the 2004 Arizona Water Settlements Act

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Abstract

In 2004 the Arizona Water Settlements Act was signed into law, which provides New Mexico and additional 140,000 acre feet of water from the Gila Basin in any ten year period. In addition, the State of New Mexico will receive $66M for "paying costs of water utilization alternatives to meet water supply demands in the Southwest Water Planning Region of New Mexico". Funds may be used to cover costs of an actual water supply project, environmental mitigation, or restoration activities associated with or necessary for the project. Further, if New Mexico decides to build a project to divert Gila basin water, the state will have access to an additional $34-$62 million. To help capitalize on this opportunity in the Gila Basin, Sandia National Laboratories, working with the New Mexico Interstate Stream Commission and the Southwest Water Planning Group has convened a collaborative modeling team. The objective of this team is to develop decision tools to support implementation of the articles of the 2004 Arizona Water Settlements Act. Specifically, an interactive water supply model will be developed to engage stakeholders and decision makers in developing plans for utilizing the water and funds made available through the 2004 Act.

Introduction

Problem Statement

In the U.S. Supreme Court litigation *Arizona v California*, 376 U.S. 340 (1964), the State of New Mexico presented evidence of present and past uses of water from its tributaries in the Lower Colorado River Basin including the Gila River and its tributaries. In addition, New Mexico presented a water supply study showing how the state could apply and use the water it claimed as its equitable share of the Gila River (Figure 1). In the resulting report of the Special Master, it was found that New Mexico should be allowed present uses as an equitable apportionment of the waters of the Gila River Basin, but did not make an apportionment of water to New Mexico to provide for future uses from the Gila.

Subsequently, the 1968 Colorado River Basin Project Act, P.L. 90-537, which authorized the building of the Central Arizona Project (CAP) included allocation of 18,000 acre-feet of water to New Mexico. This water is in addition to the water awarded in the 1964 court decree (30,000 acre-feet of consumptive use per year). The allocation was effected through an exchange by the Secretary of the Interior of 18,000 acre feet of CAP water for an equal amount of diversions of Gila River Basin water. However, the 1968 Act did not provide a means for New Mexico to divert the Gila water without objection by senior downstream users. The 2004 Arizona Water Settlements Act amends the 1968 Act and together with the Consumptive Use and Forbearance Agreement (CUFA), provides both the ability to divert without objection by downstream parties

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and the funding to help. The CUFA sets forth the rights and responsibilities of all involved parties. The CUFA also describes the terms and parameters under which diversions by New Mexico may occur without objection by the downstream parties, because additional diversions in New Mexico will be junior to all Gila rights existing as of September 30, 1968. It also describes how the Secretary of Interior will exchange CAP water for Gila basin water and how disputes may be resolved.

Specifically, the 2004 Arizona Water Settlements Act provides New Mexico 140,000 acre feet of additional depletions from the Gila Basin in New Mexico in any ten year period. In addition, the State of New Mexico will receive $66M for "paying costs of water utilization alternatives to meet water supply demands in the Southwest Water Planning Region of New Mexico, as determined by the New Mexico Interstate Stream Commission (NMISC) in consultation with the Southwest Water Planning Group (SWPG). Funds may be used to cover costs of an actual water supply project, environmental mitigation, or restoration activities associated with or necessary for the project. Further, if New Mexico decides to build a project to divert Gila basin water in exchange for CAP water, the state will have access to an additional $34-$62 million. According to the settlement, New Mexico has until 2014 to notify the Secretary of the Interior about plans to divert water from the Gila River.

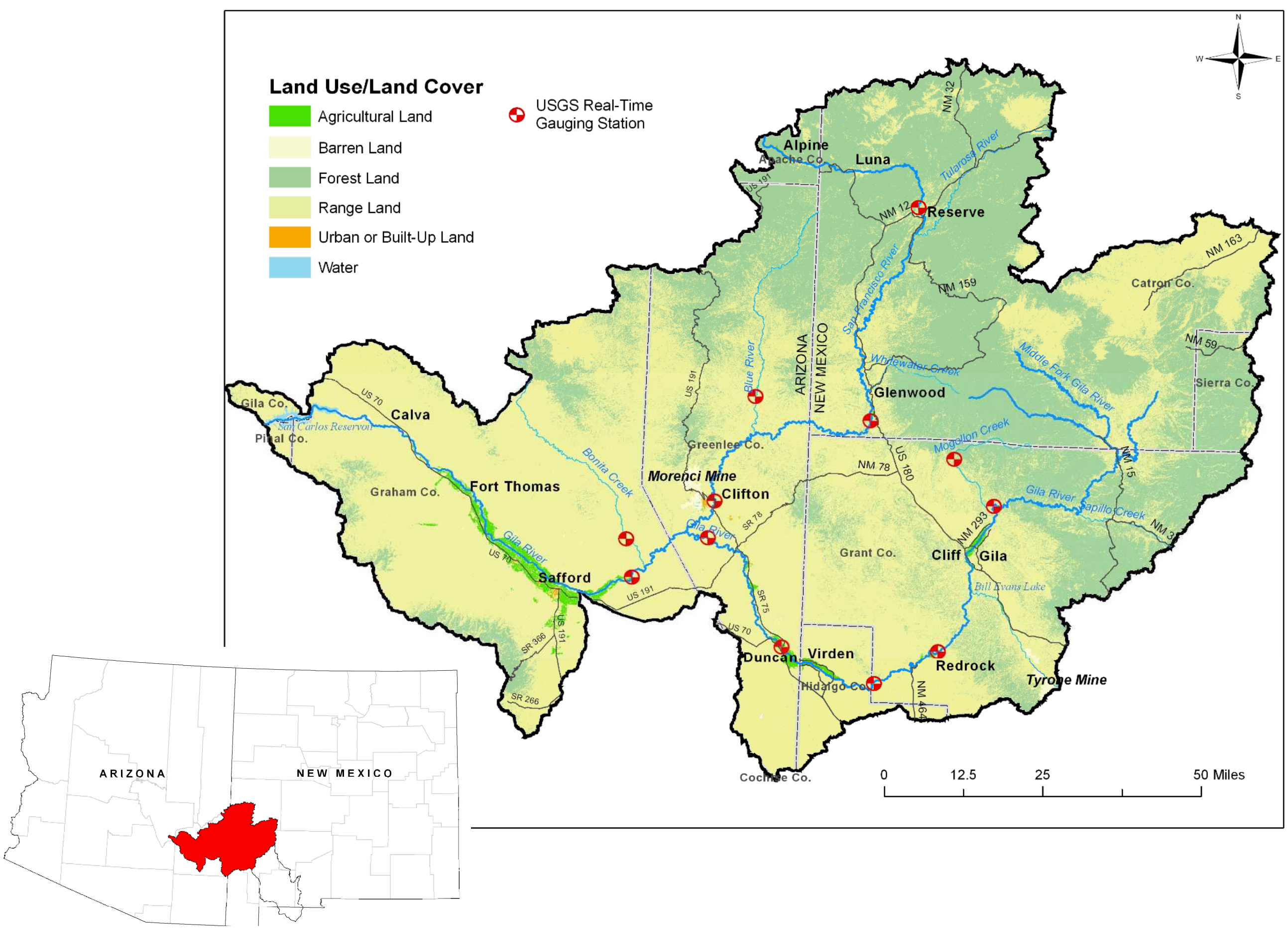

Figure 1: Map of the Gila and San Francisco River Basins. Shown are the major tributaries, gauges, and municipalities.

Environmentalists have kept a wary eye on the negotiations due to concerns about possible environmental costs if New Mexico were to develop its entitlement to the Gila River, the last main stem river in New Mexico without a major water development project. They argue that whatever diversion technique is adopted will reduce water available for wildlife, vegetation, nutrient cycling and other vital river functions. The 2004 Act requires that the NEPA process must be completed with a record of decision by 2019. The legislation designates the U.S. Bureau of Reclamation as the lead federal action agency and provides that the State of New Mexico through the Interstate Stream Commission may elect to serve as joint lead. As such the Bureau (and NMISC) will plan the formal environmental compliance activities (e.g., NEPA).

In response, the NMISC, the Office of the Governor of the state of New Mexico, and SWPG have both adopted policies that "recognize the unique and valuable ecology of the Gila Basin." In considering any proposal for water utilization under Section 212 of the Arizona Water Settlements Act, the NMISC will apply "the best available science to fully assess and mitigate the ecological impacts on Southwest New Mexico, the Gila River, its tributaries and associated riparian corridors, while also considering the historic uses of and future demands for water in the basin and the traditions, cultures and customs affecting those uses."

Now with the necessary settlements in place, decisions are needed as to how best to use the additional 140,000 acre feet of Gila water and the available funding, all before the applicable time limits expire. Ultimately, the NMISC will make that determination in consultation with the SWPG, the citizens of Southwest New Mexico and other affected interests. The New Mexico Interstate Stream Commission has committed to a continuing process of public information and comment to help arrive at such determinations.

Objective

To assist in decisions concerning implementation of the articles of the 2004 Arizona Water Settlements Act, an interactive decision support tool is being developed within a community mediated process. Specifically, the project will provide a model built from the collective knowledge and effort of a wide and disparate range of regional stakeholders, including hydrologists, ecologists, attorneys, agriculturalists, planners, and policy makers. The model will operate on a laptop computer and can be used to demonstrate key variables and processes associated with water supply/demand, tradeoffs among allocation and conservation strategies, associated consequences of alternative water use strategies, and environmental impacts. It will operate in real-time and with a user-friendly interface that includes slider bars, buttons and switches for changing key input variables, and real-time output graphs and tables showing results. These features allow a wide range of users to experiment with alternative water use strategies and learn from the results. Ultimately, the model will be distributed to users on CD or via the internet.

Methods

Two key features of this program are 1) the collaborative modeling process and 2) the resulting decision support tools. Details on each of these features are provided below.

Collaborative Modeling Approach

The watersheds in which we live are comprised of a complex set of physical and social systems that interact over a range of spatial and temporal scales. These systems are continually evolving in response to changing climatic patterns, land use practices and the increasing intervention of humans. Thus, intuition and experience alone are insufficient to effectively manage our watersheds; rather, quantitative and integrated modeling systems are required to inform the decision process.

However, developing watershed management models that are both scientifically sound and publicly acceptable is often fraught with difficulty. If such models are developed “behind closed doors”, their operation, application and utility can appear obscure to stakeholders. Rather, an open and participatory model development process can help overcome such problems by building familiarity, confidence and acceptance in the models, while allowing a more diverse group of participants to engage in the planning process. The goal is to develop tools that are a tangible manifestation of the common understanding of a wide range of stakeholders, who in turn feel a sense of common, shared ownership and confidence in the resulting models. In turn, this confidence will be conveyed to policy makers and the public contributing to widespread confidence in ensuing management decisions.

Collaborative Modeling Team:

In an effort to establish an open and transparent modeling process a “cooperative modeling team” was created consisting of representatives from each major basin stakeholder group. Specifically, we have representatives from the New Mexico Interstate Stream Commission and Southwest Water Planning Group, the U.S. Bureau of Reclamation (lead federal agency), U.S. Fish and Wildlife (responsible for Endanger Species Act compliance), major municipalities, irrigated agriculture, ranching and the environment. Modelers from Sandia National Laboratories (SNL) are responsible for model development, while a professional facilitator and meeting note taker are responsible for managing the flow of each meeting. In all, there are roughly 20 active members on the team.

The cooperative modeling team was formed in September of 2005 and has been meeting since this time. Meetings are held every other Wednesday morning. Because of the wide geographic dispersion of the team members meetings are held via web/voice conferencing. In addition, quarterly face to face meetings coinciding with the monthly SWPG meetings are held to help build a sense of team among the members while giving the general public an opportunity to stay informed and give feedback into the process.

At the meetings, the team helps the modelers with system conceptualization, identification of subject expertise, data sources, and provides feedback on the modeling efforts. Very significantly, the team raises important modeling considerations based on the experience and concerns of their constituency. Between meetings the SNL modelers incorporate information gleamed from the team into the model, which is then reviewed by the team at subsequent meetings.

A project website (https://waterportal.sandia.gov/nmstateengineer) provides another vehicle for team interaction. Meeting notes, data, maps, and literature which are of interest to the program are uploaded to this site by any team member. In this way, all team members can keep up to speed on the latest project developments. Although access to draft data and models is restricted to the modeling team all other information is fully available to the public. Thus, this website provides a means for the broader public to stay informed on model progress.

While time consuming and difficult, this approach ensures that stakeholders in the four-county area have an opportunity to see that their interests are included in the model. The approach also allows any interested individual to learn about how the model is built and how it works. This transparency is believed to be a key for developing model credibility and usefulness.

Collaborative Modeling Tools

Selection of the appropriate architecture for the decision model is based on two criteria. First, a model is needed that provides an "integrated" view of the watershed — one that couples the complex physics governing water supply with the diverse social and environmental issues driving water demand. Second, a model is needed that can be taken directly to the public for involvement in the decision process and for educational outreach. For these reasons we adopt an approach based on the principles of system dynamics (Forrester, 1990; Sterman, 2000). System dynamics provides a unique framework for integrating the disparate physical and social systems important to water resource management, while providing an interactive environment for engaging the public.

System dynamics is a systems-level modeling methodology developed at the Massachusetts Institute of Technology in the 1950s as a tool for business managers to analyze complex issues involving the stocks and flows of goods and services. System dynamics is formulated on the premise that the structure of a system – the network of cause and effect relations between system elements – governs system behavior (Sterman, 2000). "The systems approach is a discipline for seeing wholes, a discipline for seeing the structures that underlie complex domains. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots, and for seeing processes rather than objects" (Simonovic and Fahmy, 1999).

In system dynamics a problem is often decomposed into a temporally dynamic, spatially aggregated system. The scale of the domain can range from the inner workings of a human cell to the size of global markets. Systems are modeled as a network of stocks and flows. For example, the change in volume of water stored in a reservoir is a function of the inflows less the outflows. Key to this framework is the feedback between the various stocks and flows comprising the system. In our reservoir example, feedback occurs between evaporative losses and reservoir storage through the volume/surface area relation for the reservoir. Feedback is not always realized immediately but may be delayed in time, representing another critical feature of dynamic systems.

There are a number of commercially available, object-oriented simulation tools that provide a convenient environment for constructing system dynamics models. For purposes of this project Studio Expert 2007, produced by Powersim, Inc. is used. With this tool model construction proceeds in a graphical environment, using objects as building blocks. These objects are defined with specific attributes that represent individual physical or social processes. These objects are networked together so as to mimic the general structure of the system, as portrayed in a causal loop diagram. In this way, these tools provide a structured and intuitive environment for model development.

Model Description

Model development follows a four-step process. First, the problem to be solved and the scope of analysis are defined. Second, a description of the system is developed. This step begins by conceptualizing the broad structure of the system, followed by decomposing that structure into a series of manageable units defined by specific system sectors (e.g., agriculture, mining). For each sector a causal loop diagram (e.g., Sterman, 2000) describing the inherent structure and feedback is developed and reviewed by the cooperative modeling team. Subject experts are identified by the modeling team who are then contacted for further clarification of the system and to gather necessary input data. In the third step, the causal loop diagrams are converted into a system dynamics context, and model sectors are populated with appropriate data and mathematical relations. Step four involves model calibration against historical data followed by review. The modeling team reviews the model as it evolves through these stages.

The basic model addresses principle water supply and water demand sectors within Southwestern New Mexico. A model schematic for a representative reach is given in Figure 2. The model is structured according to seven broad sectors, surface water, groundwater, land surface processes, institutional controls, environmental, water use, and future water utilization options. Model simulations are conducted on a daily time step over a variable planning horizon. Spatially, the model is disaggregated according to river reaches as defined by active gauging stations (Figure 1). There are a total of five reaches on the Gila River and three on the San Francisco River.

Surface Water System
The surface water system considers the Gila and San Francisco Rivers above the Gila gage at Safford (Figure 1). Flow between gages is simply routed by a time delay coefficient based on the river discharge. Gains to the river include tributary inflows, groundwater gains and agricultural return flows. River losses include groundwater leakage and evaporation. Diversions from the river include water for irrigated agriculture (all reaches) and for mining (one reach).

Groundwater System
Each river reach is accompanied by two groundwater reaches, one fluvial aquifer and one regional aquifer. Groundwater flows are modeled between adjoining reaches, between the fluvial and regional aquifer and between the river and fluvial aquifer. Flows are driven by differences in fluid potential as represented by differences in hydraulic head. Gains to the regional aquifer are limited to distributed recharge while losses include municipal/agricultural pumping and losses to the fluvial aquifer. Fluvial aquifers receive inflow from irrigation seepage, irrigation canal leakage, and the regional aquifer, while losses occur by riparian evapotranspiration, pumping and river discharge.

Land Surface System
Precipitation falling on the contributing watershed must be partitioned into soil moisture, distributed recharge, surface runoff, or evaporative loss. The land surface model provides these

calculations. The calculations are spatially distributed according to the primary gauged and ungauged tributaries to the Gila and San Francisco Rivers. Each tributary watershed is disaggregated into hydrologic response units (HRUs) based on differing soil and vegetation types. In each HRU precipitation can be captured by the vegetation canopy, infiltrated into the soil, or when the infiltration capacity is exceeded, runoff is generated. Infiltrated water can either drain to the regional aquifer (i.e., distributed recharge), move as interflow to the local tributary, or be lost by evaporation or transpiration. Surface runoff is routed according to a simple Manning's equation to the outlet of the tributary.

Institutional Controls

There are three basic institutional controls on the Gila Basin. The 1968 Supreme Court Decree limits total water consumption in the New Mexico Unit of the Colorado Basin to 30,000 AF/year. Additionally, the Gila basin has been adjudicated, thus a system of senior water rights as applied at the irrigation ditch level constrains water delivery priorities throughout the basin. Finally, the Consumptive Use and Forbearance Agreement (CUFA) stipulates when, how much, and where Arizona Water Settlements water can be taken from the system. Each of these three levels of controls are implemented within the model.

Environmental

Environmental concerns within the basin primarily involve riparian vegetation and the aquatic ecosystem. The model addresses the extent and composition of the riparian vegetation then tracks its impact on the available water supply. Aquatic habitat is primarily addressed by tracking various flow targets at critical subreaches within the basin. Both low flow and flood target levels are tracked.

Water Use

Temporally varying water demands are calculated for the Gila, San Francisco, Mimbres and Animas basins. The Mimbres and Animas are included here as municipalities in these basins are also included as potential recipients of Arizona Water Settlements Act water. Specific demands include agricultural, livestock, industrial, mining, and commercial/residential. Agricultural demands are modeled as a function of the crop, acreage, climate and adjudicated water right. Livestock demand is calculated according to the type of operation (farm vs. open-range), number of head of cattle and the water right. Industrial/mining uses are modeled according to past uses and their adjudicated right. Municipal/commercial uses are modeled according to population, per capita use and the adjudicated water right. Water uses in each case are modeled individually for each municipality in the region and by county for domestic well users.

Future Water Utilization Alternatives:

The final step in the modeling process will be to construct alternative water uses for the Arizona Water Settlements Act water and funding. Identification of such alternatives is still in progress. Examples of potential projects might include construction of an off-stream storage reservoir on the Gila River, an artificial recharge project, forest thinning, or improved irrigation efficiency.

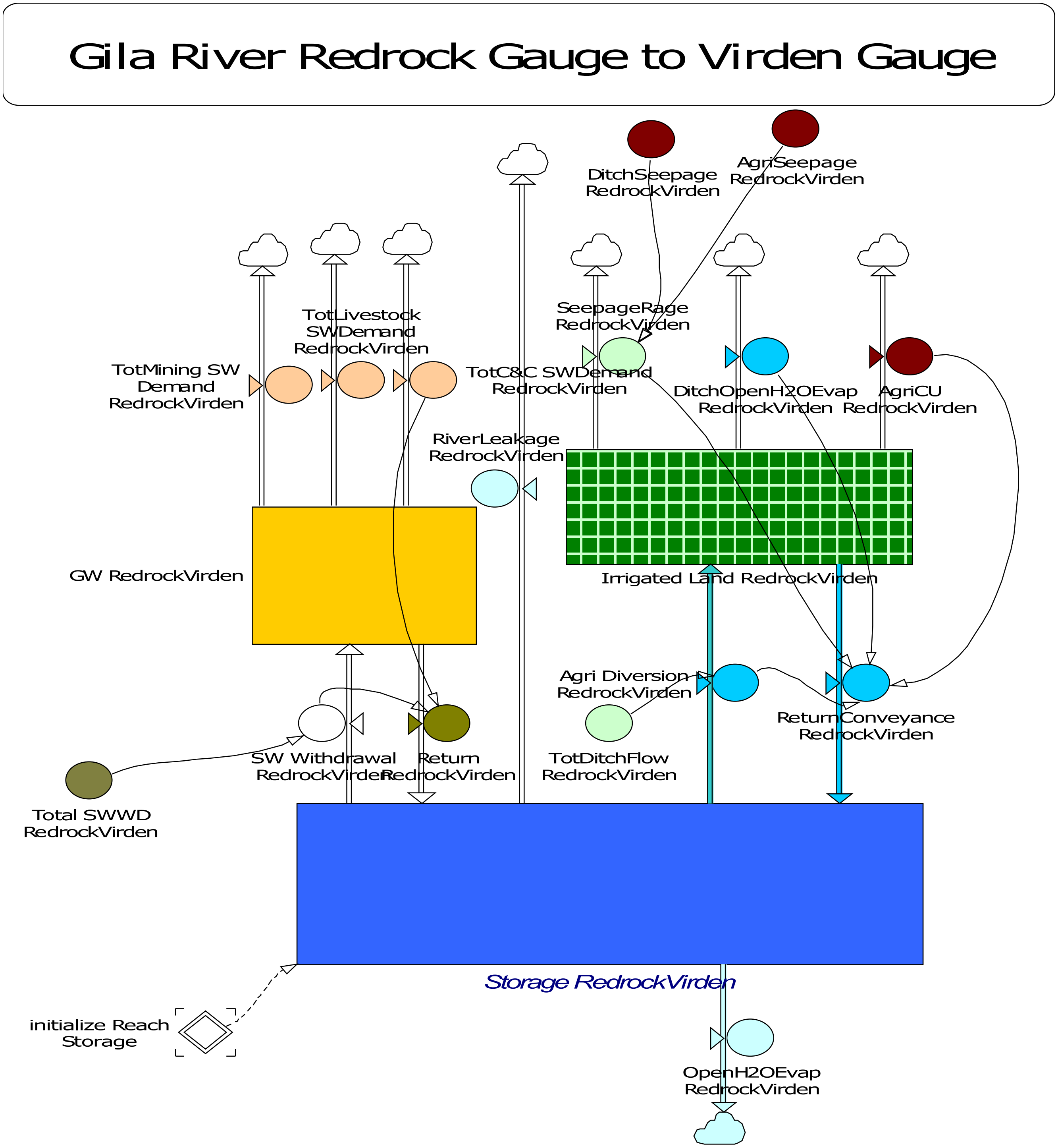

Figure 2: Model schematic for a representative reach of the river. Symbols follow standard system dynamics form.

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