The Future of Energy and Minnesota's Water Resources

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Glossary and definitions

Water use: withdrawal of water for specific sectoral purpose, i.e. industrial, agricultural or domestic (can be applied to describe either water withdrawal or water consumption)

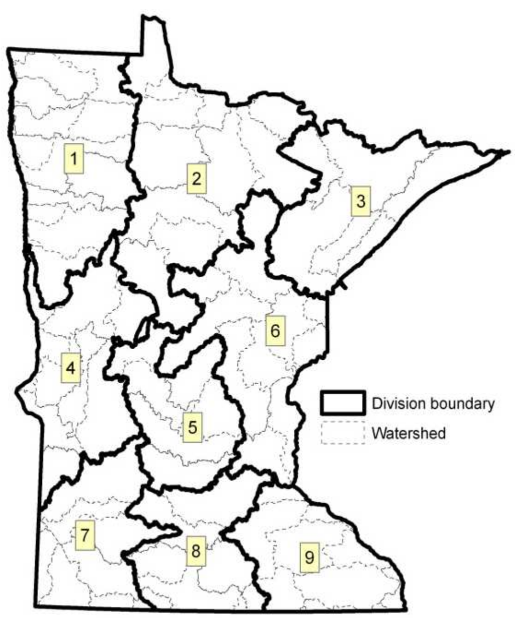
Water withdrawal: the removal of freshwater from water resources or reservoirs for use in agriculture, industry or domestic purposes, in which part of the water returns to the origin water source of extraction and the rest is lost through evaporation or due to significant quality degradation

Water consumption: the use of water by humans from natural water resources or reservoirs for agriculture, industry or domestic purposes, which is consequentially lost and not available for other consumers or biota through evaporation or due to significant quality degradation

Water availability: the amount of water entering surface water bodies and groundwater systems, which is the maximum theoretical water quantity available in a certain area during a specific time period

Water demand: the need for water in supporting agricultural, industrial, public or domestic activities, which is presented as water withdrawal

Water stress index: the fraction of total water withdrawal in total available water



Map of divisions (1 – 9) used in this report.

Divisions 1 – 3: North
Divisions 4 – 6: Central
Divisions 7 – 9: South

Divisions 1, 4, 7: West
Divisions 2, 5, 8: Central
Divisions 3, 6, 9: East

Summary of scenarios tested in this study

Scenario	Description of assumption				
	Description	Climate	Population	Ethanol	Power
BL	Baseline case in year 2000	—	—	—	—
CnBAU	Business-as-usual scenario by 2030	—	N	N	N
CxBAU	Business-as-usual plus climate change scenario by 2030	X	N	N	N
Cx	Climate scenario by 2030	X	—	—	—
PPn	Population scenario by 2030	—	N	—	—
EtOHn	Ethanol production scenario by 2030	—	—	N	—
PWn	Power generation scenario by 2030	—	—	—	N
Extreme	Extreme scenario by 2030	X	X	X	X

—: current average status in 2000s
N: business-as-usual scenario
X: extreme scenario

Executive summary

With new bioenergy policies aiming to reduce fossil fuel dependency, Minnesota has become one of the top five bioethanol producers in the United States in the past two decades. Bio-energy production, together with increasing population, energy demand and climate uncertainties, present a great challenge for water authorities seeking to sustainable future water supply. This report aims to envision Minnesota's temporal and spatial water schemes by 2030 in response to population, energy, and climate scenarios, by integrating a system dynamics model with geographic information system (GIS) data. The results indicate that population growth and increasing demand on electric power generation are two primary factors driving increasing future water demand in Minnesota. Water management should be coupled with urban development and planning to reduce water stress induced by population growth and electric power generation. Late summer and winter are two periods of time in which it is particularly challenging to support human demand of water without the potential of drawing down the water resources. This report presents maps and regional monthly water availability graphs for various scenarios tested in this study. These system characteristics shown in the current scenario analysis can play an important part of future water conservation and management planning.

1. Background

Minnesota's water resources are critical to the state's economy, ecology and culture. There is a common perception that Minnesota is a water-rich state, but in fact the state's water resources are highly heterogeneous. Rates of groundwater recharge, precipitation, and evapotranspiration, which determine the amount of water available for human and ecosystem use, vary considerably throughout the state. Furthermore, there are several major changes that are likely to occur or are already occurring in Minnesota, which will impact the water budget in a spatially heterogeneous manner. These include demographic change, climate change, biofuel development, and electricity grid-mix change.

Another rapid change with significant implications for water is biofuel development. Water for ethanol production is currently a very small portion of overall water use in Minnesota, but if ethanol production expands, water demands could exceed supply in some regions of the state. Under the ethanol blending mandates in place, Minnesota will need to produce (or import) over 2 million m^3 of ethanol annually by 2013, according to the state Department of Agriculture [1]. Economic incentives could drive this production number even higher. This corresponds to approximately 8 million m^3 of water needed for processing, assuming the ethanol is made from corn grain; it becomes 13 million m^3 of water if the ethanol blending mandate is met using cellulosic feedstock processed via enzymatic methods [2]. There are some technological options for reducing these water requirements by up to 20%, but these innovations are associated with a higher capital cost [3]. If irrigation needed for corn production is factored into ethanol water requirements, Minnesota's water demand for ethanol production climbs to over 40 million m^3 by 2013 [4]. Currently, only a small percentage of Minnesota corn is irrigated, but this could change if corn expands onto marginal lands. In the United States, energy crops for biofuel production are currently not irrigated. However, irrigation may be necessary as biofuel feedstock demand expands depending on the type of crops and the location of production. Miscanthus, for example, requires more water than corn [5].

Considering the 5.3 billion m^3 of state water use budget, water demand for biofuel production (which is only several million m^3) may not be significant. However, for certain localities ethanol production may be enough to overwhelm local groundwater resources when combined with other competing industrial and municipal uses. This is a serious possibility, given the fact that most current and proposed ethanol plants are located in relatively water-poor regions of the state, particularly southwest and south-central Minnesota. Plans to construct a corn-based ethanol plant near Pipestone were stopped in 2005 because of concerns over water supply [6]. Mixed prairie grasses, another option being considered for ethanol feedstock in Minnesota, may have fewer impacts on local water resources, but it is important to test this hypothesis with a model [7]. All biofuel options involve some degree of land cover change, which impacts the hydrology of local systems [8].

Another important change relevant to the state's water future is demographic change. Population growth in Minnesota is slowing overall, but like other trends it will occur in a spatially heterogeneous manner. The Central Lakes and greater Metro region is expected to experience population growth, while many rural areas of the state may lose population [9] (Figure 1.1). Municipal water use per capita has increased in Minnesota since the 1950's, implying that the efficiency of water use by people and households in urban areas is not improving. This trend is opposite to the pattern seen in most parts of the United States, where water consumption rates are not growing as fast as the population [10]. Minnesota's increasing water consumption, combined with spatial patterns of population growth, may lead to significant stress on water resources [11].

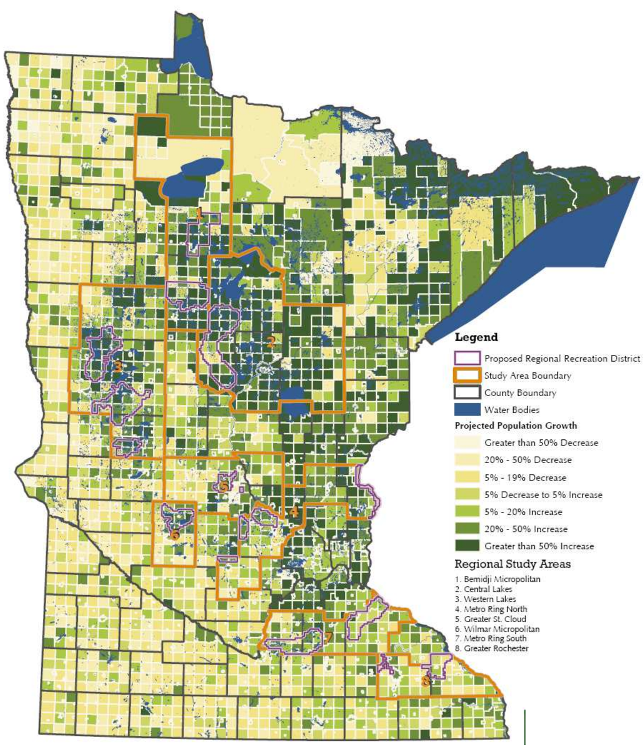


Figure 1.1 Map of expected population growth between 2005 and 2030 (Source: MN State Demographer's Office. Map prepared by Mike Wietecki).

These important changes that the state is likely to undergo will by and large shape the future of the state's water environment. Given that these changes are spatially heterogeneous, it is important to account for spatial dimensions when analyzing the implications of these changes on water resources.

An important dimension of complexity in understanding the state's water availability is seasonality; water availability of a region depends on seasonal changes of water supply and demand. Therefore, an explicit temporal dimension is essential in understanding future water availability. For instance, climate change is projected to increase overall precipitation in Minnesota, with a disproportionate amount of this increase occurring during the late fall and early winter [12, 13]. This may not be an unqualified boon for the state's water resources, however, as more of this precipitation is expected to occur during heavy rains and storm events, potentially increasing rates of drought and flooding [14]. Additionally, evapotranspiration, which is highly seasonal, is expected to increase in the upper Midwest, which may negate the precipitation water gains [15].

Given these rapid changes that are taking place in Minnesota with spatial and temporal dimensions, there is a need to develop a tool for evaluating the impacts of these changes on the state's water resources. Such a tool would enable integrated and holistic water planning as recommended in the Minnesota Statewide Conservation and Preservation Plan and previous documents [16].

In this report we analyzed the combined effect of future changes in demographics, energy environment and climate on Minnesota's water resources using a state-wide water balance approach coupled with a spatially and temporally explicit modeling framework. Our modeling approach was established to help envision the future of water resources in Minnesota for policy development and planning.

2. Major trends

2.1. Overall water use in Minnesota

Overall water use in Minnesota has been generally increasing for the last two decades (Figure 2.1). The largest increase in water use in Minnesota has been due to an increase in electricity generation. Industrial water use and irrigation water use are relatively small in the overall picture of the state's water use.

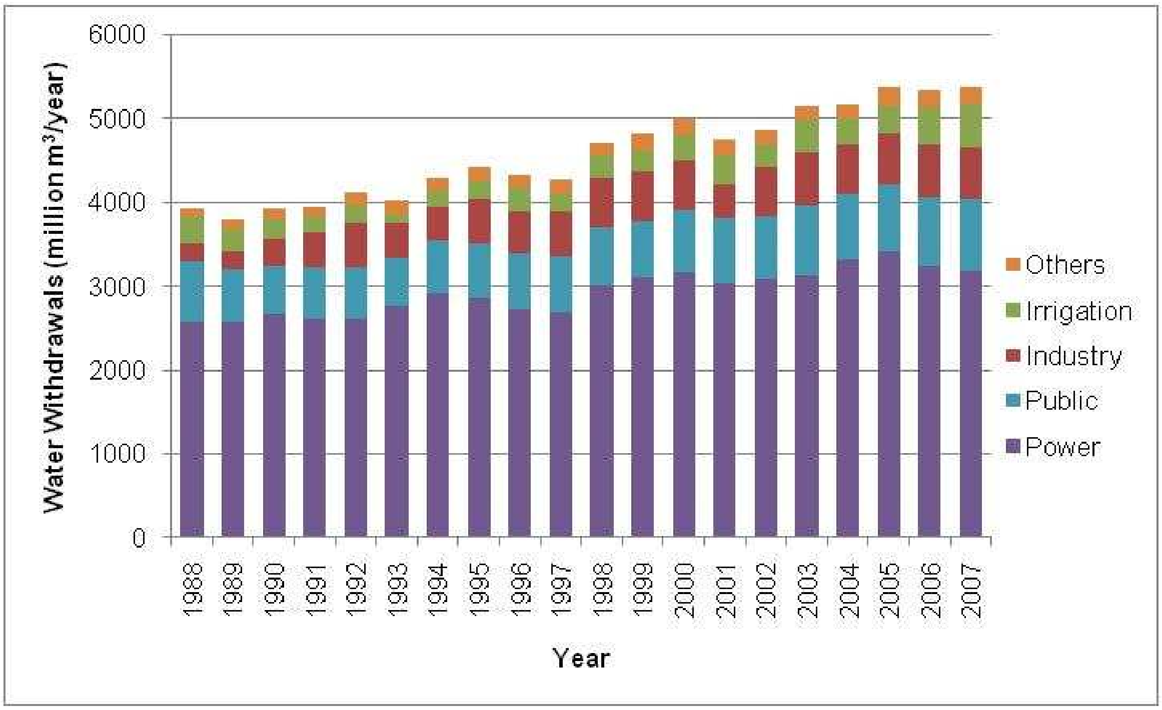


Figure 2.1 Trend of water withdrawals in Minnesota by user category [17].

2.2. Power generation and water consumption

Electric power is responsible for over 36% of national total fresh water use, of which thermoelectricity (water cooling associated with coal and nuclear electricity) requires the largest portion [18]. Estimated water use for thermoelectric power production showed steady increase from 1950 to 1980, and declined more than 11% from 1980 to 1985. The trend has remained relatively stable with less than 3% change since 1985 (Figure 2.2).

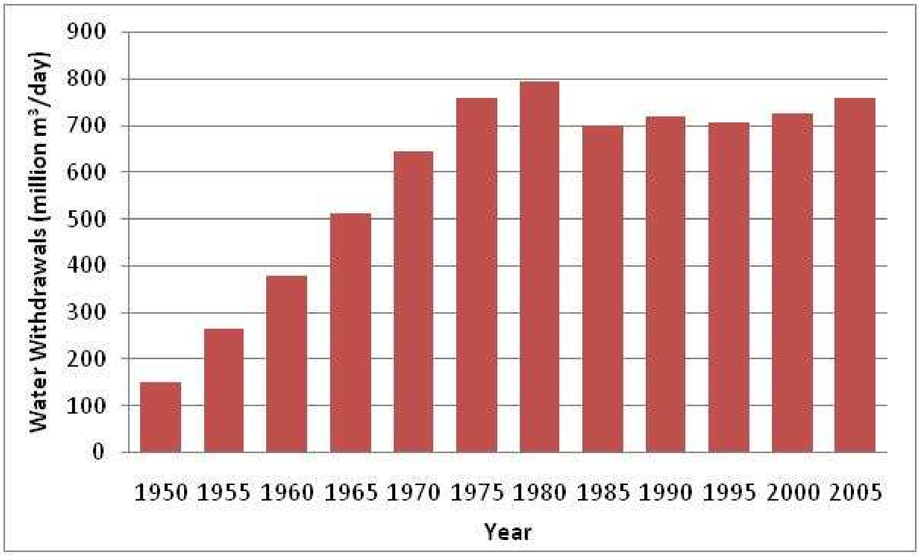


Figure 2.2 Water withdrawal trend in the thermoelectric power category in the U.S. [18].

Water use efficiency of a power plant varies widely depending on the driving fuel and cooling systems. A prior study claimed that hydroelectric power has the highest water use efficiency, consuming 0.4 m^3 of water per MWh [19]. Fossil fuel thermoelectric power, whichrepresents the largest segment of U.S. electricity production, consumes 14 – 28 m^3 of water per MWhr. Nuclear power, on the other hand, is the least water efficient type of power generation, consuming 30 – 75 m^3 of water per MWh. However, these figures are valid only under certain assumptions. For example, if water loss through evaporation from reservoirs is included in the diagram, hydropower would consume 27 times more water than nuclear power and 34 times more than coal-fired power [20].

2.3. Biofuel and water consumption

With a strong U.S. national interest in energy independence, biofuels have become important transportation fuels. Therefore, the production and use of biofuels is growing rapidly in the U.S. from 5 million m^3 in 1995 to 34 million m^3 in 2008 (Figure 2.3). The Energy Independence and Security Act (EISA) of 2007 set biofuel production goals through 2022. The bill mandates that "conventional biofuels" such as corn grain ethanol attain maximum production of 57 million m^3 per year by 2015. Beginning in 2016, the production capacity of "advanced biofuels", which use non-food sources such as cellulosic biomass and algae, should be increased by 11 million m^3 , reaching 79 million m^3 by 2022.

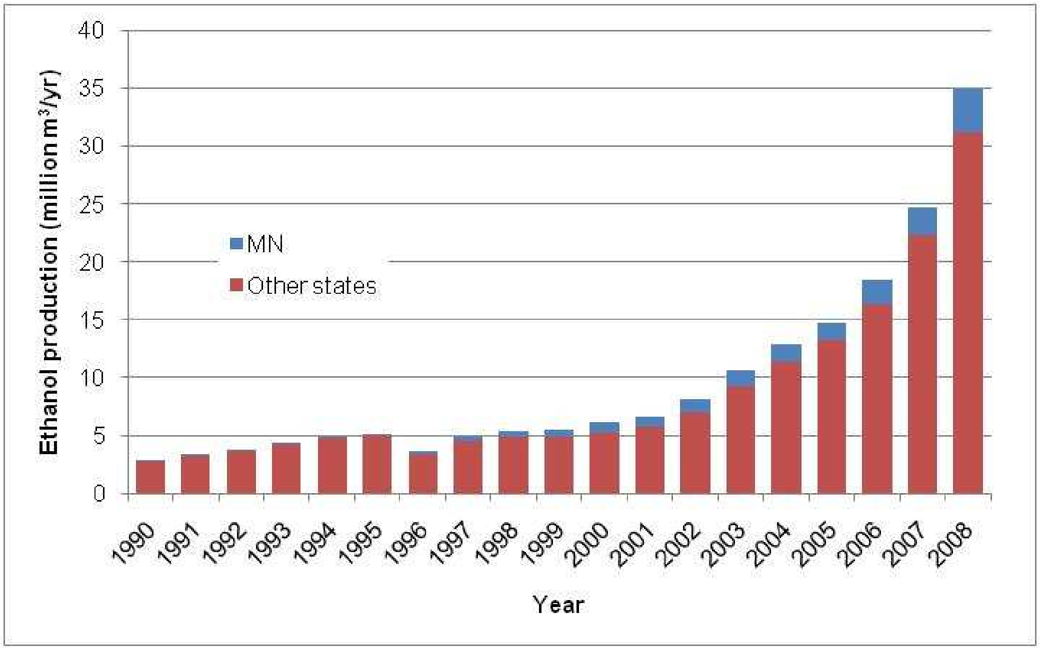


Figure 2.3 Historical U.S. Bioethanol and Biodiesel Production [21].

Existing studies are inconsistent regarding the implications of biofuel development for state water consumption. These inconsistent results are largely the result of the spatial scale selected in an assessment. For example, on a national average, one m^3 corn ethanol may require 263–780 m^3 of water, in which only 3.3–40 m^3 of water are attributed to process water and the rest is acquired for irrigation [22, 23]. On a regional scale, a prior study concluded that corn ethanol consumes 10–324 m^3 of water per m^3 production with significant regional differences [24]. However, if the data are broken down to a state level, the variances can be much greater than what was previously estimated and result in a wide spectrum of water consumption estimates from 5 to 2,100 m^3 of water per m^3 ethanol production (using two significant digits) [4].

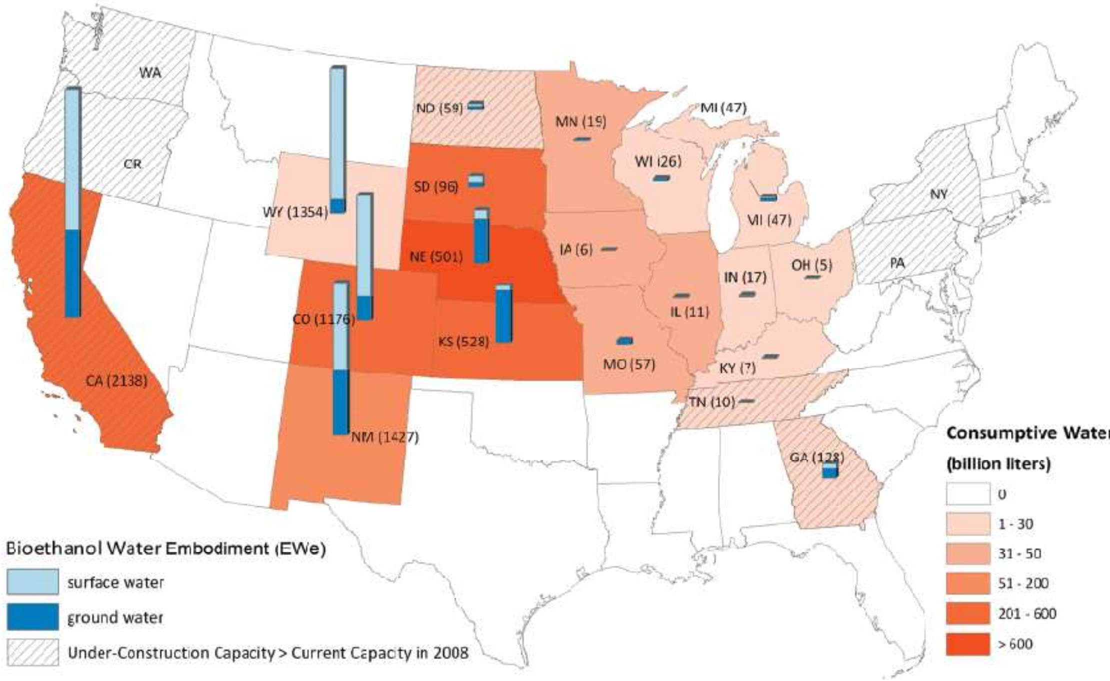


Figure 2.4 Water embedded in corn-based ethanol (denoted in parentheses, in m^3 water/m^3 ethanol or liter water/liter ethanol) by state. Background color indicates the total water consumed by ethanol in year 2007 (the original map was published in *Environmental Science and Technology* [4]).

3. Water balance method and data

Water balance is a system level analysis based on total water inflow and outflow of a region, which determine the change in water stock of the region over time. Water balance is based on themass balance principle. Water as a compound can be created or destroyed as a result of biochemical reactions, such as combustion. Therefore, strictly speaking, water mass is not a conserved quantity. However, the amount of water created or destroyed via chemical reactions is relatively small compared to major water flows such as precipitation and evapotranspiration, and is negligible in the natural water cycle diagram [25-29]. In this case, water balance can be expressed using an equation:

$$\Delta S = P - ET - Q,$$

where *P* is precipitation, *ET* is evapotranspiration, *Q* is net surface water outflow, and ΔS is the change in water storage in top soil and aquifers. On a long-term basis over a large area, ΔS is minimal if the system reaches its equilibrium without significant disturbance [25]. Positive ΔS

indicates that the system is accruing water stock over time, and negative ΔS indicates that the system is draining water stock over time.

The water balance calculation helps us to understand water availability in a region [26, 27]. The amount of precipitation, which is a major water inflow, minus the amount of evapotranspiration, which is a major water outflow, is often referred to as “water supply index” [28]. Water supply index indicates the amount of maximum available water for a region, and this approach has been widely applied in studying global water availability since the 1980s. The ratio of regional anthropogenic water withdrawal to the maximum available water is widely referred to as “water stress index”, which has been used to indicate the water scarcity of a region [29, 30].

An alternative approach of maximum water availability calculation is based on stream flow. Total stream flow is the sum of surface runoff and the base flow discharged from groundwater. As stream flow occurs when a region cannot hold or use incoming water to the region, total stream flow is indicative of the maximum available water [31].

In traditional hydrological models, anthropogenic water withdrawals were often left out of the modeling framework [32]. However, prior studies found that human appropriation of renewable water resources can be as significant as 35% to 42% of total renewable water available to the region [33, 34]. Therefore, instead of simulating the “natural” status of the water balance, we integrated anthropogenic water supply and demand in the modeling framework in order to present a more realistic water balance (Figure 3.1).

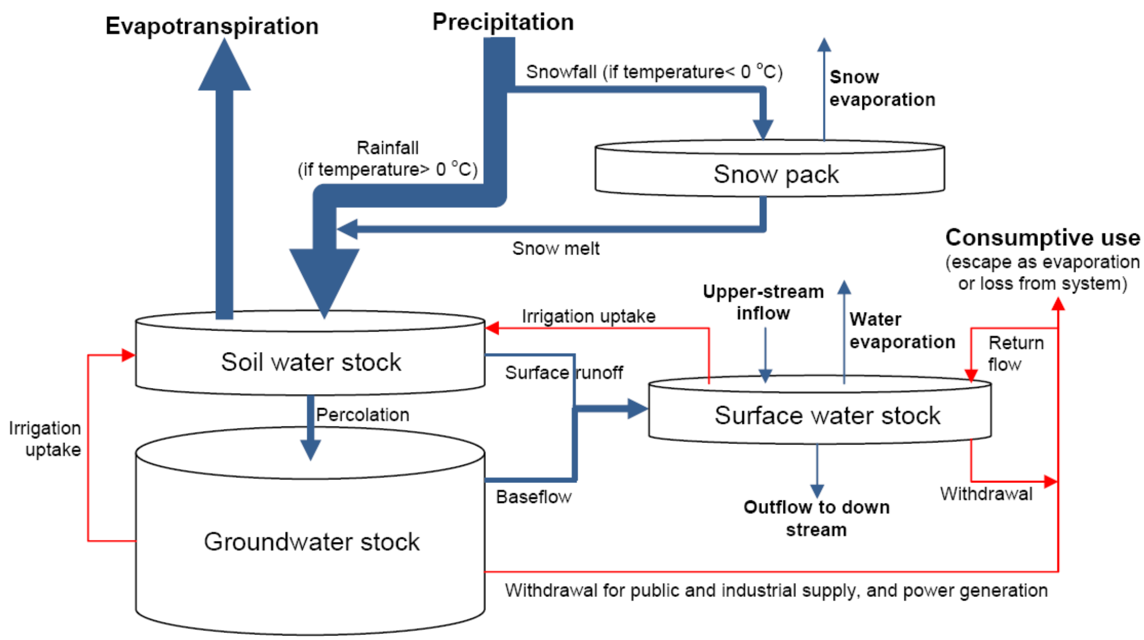


Figure 3.1 Conceptual water stocks and flows diagram. Bold-font flows indicate the primary flows entering and leaving a watershed, which is the spatial unit and system boundary considered in this report (lines in red color indicate anthropogenic flows).

3.1. Maximum available water

Minnesota receives little surface water from adjacent states and sends more surface water to neighboring states than it receives. Therefore, the maximum available water within the state boundary is made up of the surface water runoff generated in Minnesota and the ground water recharge occurring in Minnesota. Theoretically, water availability can be estimated by computing water balance in the soil layer and using the sum of surface runoff and percolation occurring in the soil as an indicator (Figure 3.2). This approach describes the maximum water occurring in the system before anthropogenic water use.

Water percolating through the soil layer becomes the primary recharging flow to groundwater stocks, which can significantly influence stream flow by discharging groundwater into stream systems as baseflow. Thus, prior large-scale studies have often selected stream flow as an indicator of maximum available water [26, 35, 36]. However, this method is only applicable when anthropogenic withdrawals from groundwater stocks are negligible.

For the purpose of verification, we compared historical stream flow data and estimated water availability, and both approaches yield a total amount of annual water availability of 151 to 159 mm per year in Minnesota (Figure 3.3). However, the difference between stream flow and estimated available water is expected to increase as human influence on hydrology increases.

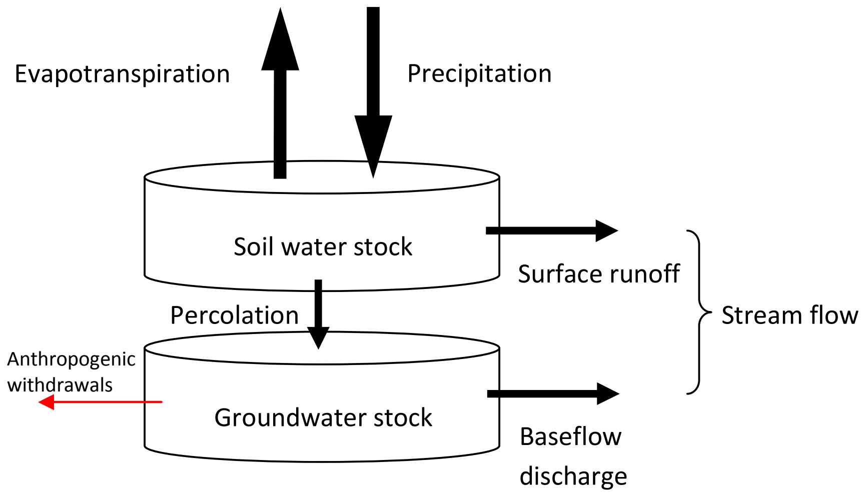


Figure 3.2 Conceptual diagram of estimating water availability. The sum of runoff and percolation indicates the maximum theoretical available water by eliminating the anthropogenic effects caused by water withdrawals from the groundwater systems.

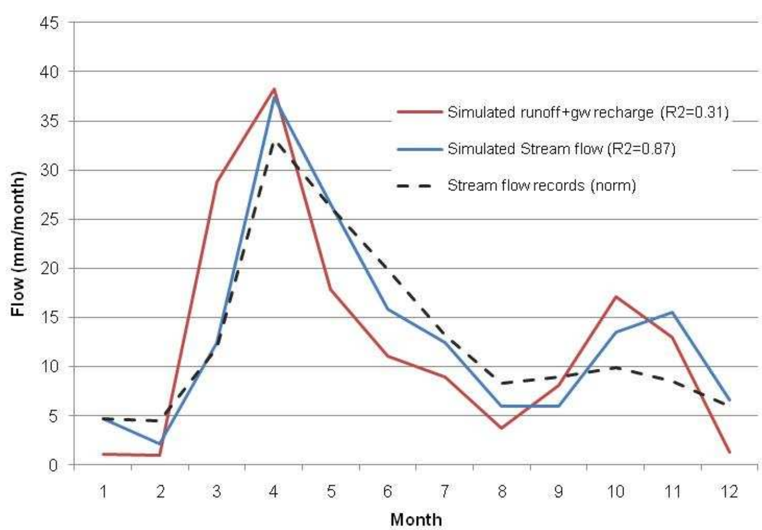


Figure 3.3 Comparison of results from different approaches in determining water availability. Both approaches show similar temporal trends and differences in the annual sum are less than 5%.

3.2 Seasonal dynamics of water withdrawals

In this report, the terms, “water consumption” and “water withdrawal” are distinguished. Water consumption is defined as the amount of water withdrawn which does not return to its original source in a watershed due to evaporation, transpiration, or significant degradation in quality and is no longer available for biological uses in the same watershed. Water withdrawal, on the other hand, accounts for the total water volume extracted from a watershed from rivers, lakes, man-made reservoirs, and aquifers. Therefore, water withdrawal should be equal to or greater than consumption. For description purposes, all results are grouped into 9 divisions based on Minnesota climate characteristics (Figure 3.4).

Historical data indicate that Minnesota’s water withdrawal has gradually increased in almost every use category since the 1980s [17], and has shown little sign of decline (Figure 3.5). Spatially, different regions show significant variance in each use category, and Minnesotans withdraw 2% to 30% of available water on average (Figure 3.6). For instance, water extracted for supporting power generation is one of the top withdrawal categories, especially in south-east Minnesota. This region (Division 5, 6, 8, and 9 in Figure 3.4) is also responsible for 51%, 80% and 82% of state total irrigated, public and domestic, and power generation water withdrawals, respectively. However, industrial withdrawal plays an important role in north-east Minnesota, where Division 2 and 3 alone withdraw more than 81% of state industrial water.

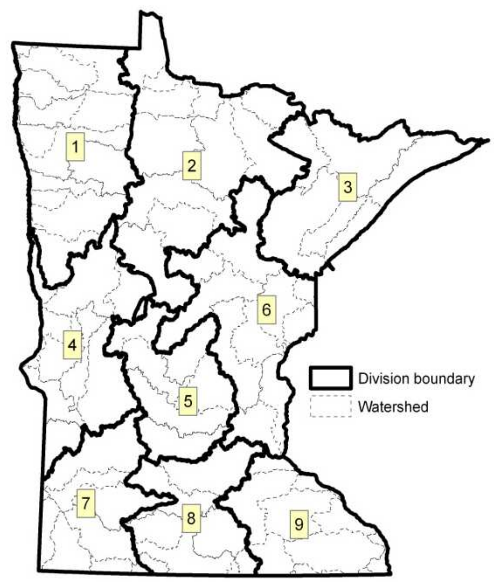


Figure 3.4 Division numbering and location.

As Figure 3.4 illustrated, the peak water availability normally occurs around spring, whereas water withdrawal peaks in summer due to the intensive water withdrawal from power, residential and agricultural sectors [37-39]. The impacts of this withdrawal may seem to be minimal and unrecognizable unless significantly dry years occur in Minnesota. The 1988 summer drought in Minnesota, for example, forced the water authority to suspend irrigation water permits in 13 watersheds which primarily extracted water from surface water sources [40]. The drought caused an average reduction of 41% in crop yield from previous year, and destroyed

80% of newly planted trees in central Minnesota [40]. Power generation also declined by 26% [40].

Therefore, to understand the relationship between the aspects of water withdrawal and water availability on both spatial and temporal scales, it is necessary to establish a holistic framework coupling these two aspects. In the next section, we introduce a modeling framework which takes water demand and supply into account with detailed spatial and temporal resolution.

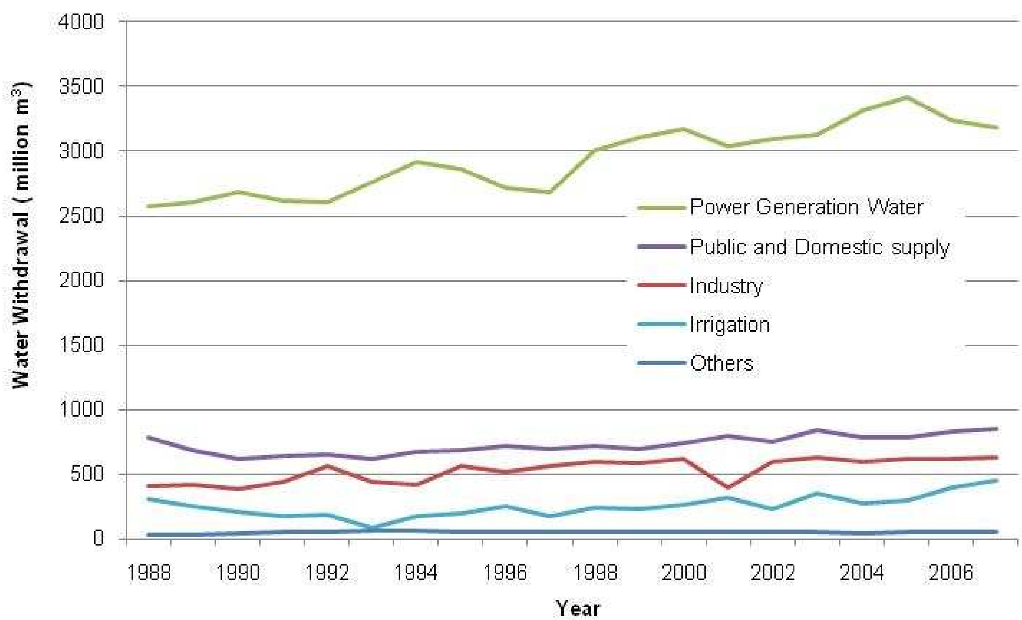


Figure 3.5 Water withdrawals have been climbing gradually in every use category. Power generation has been the major withdrawal category, r demanding five times more water than the others.

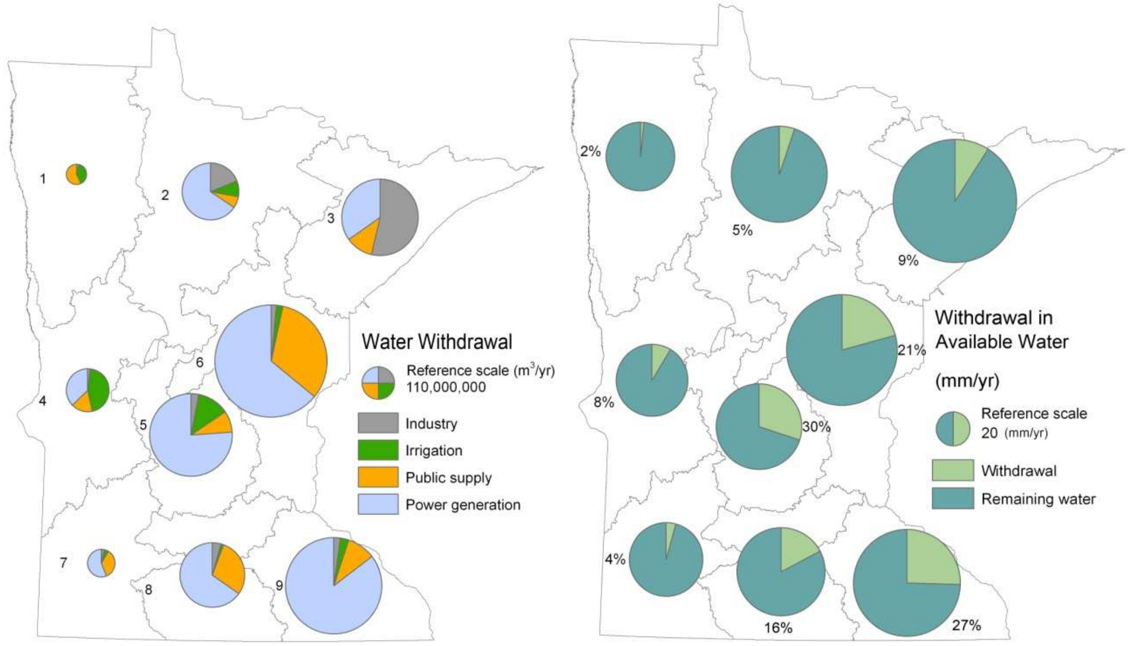


Figure 3.6 Water withdrawal (left) and water withdrawal as a percentage of total available water (right) in different divisions. The pie size indicates the total volume of annual water withdrawal in a division on the left and total available water on the right. The spatial distribution is highly correlated with population distribution and local economic activities.

4. Integrated analytical framework incorporating system dynamics

A modeling framework integrating system dynamics modeling and GIS was established to assess regional water availability in the future. In this section, we derive several key drivers which shape regional water regimes, and describe the tool we established to assess the change in regional water regimes under different scenarios.

4.1. Drivers of change

Several major changes are likely to occur or already occurring in Minnesota that can potentially impact the water budget. These include demographic change, climate change, biofuel development, and electricity demand. The modeling framework established in this study was developed specifically to evaluate the impacts these changes will have on water resources, so that water use planning may become more integrated and holistic with a focus on sustainability, as recommended in the Minnesota Statewide Conservation and Preservation Plan and previous documents [16].

4.2. System dynamics model

To transform the conceptual diagram in Figure 3.1 into a numerical matrix, a series of hydrological, climatic, socio-economic, and stochastic models were connected as a holistic modeling framework by using system dynamics software as a platform. The framework was further divided into four modules including climate, energy demand, water demand, and water balance (Figure 4.1). The model is described in detail below, and a programming structure developed in Vensim® can be found in Appendix I.

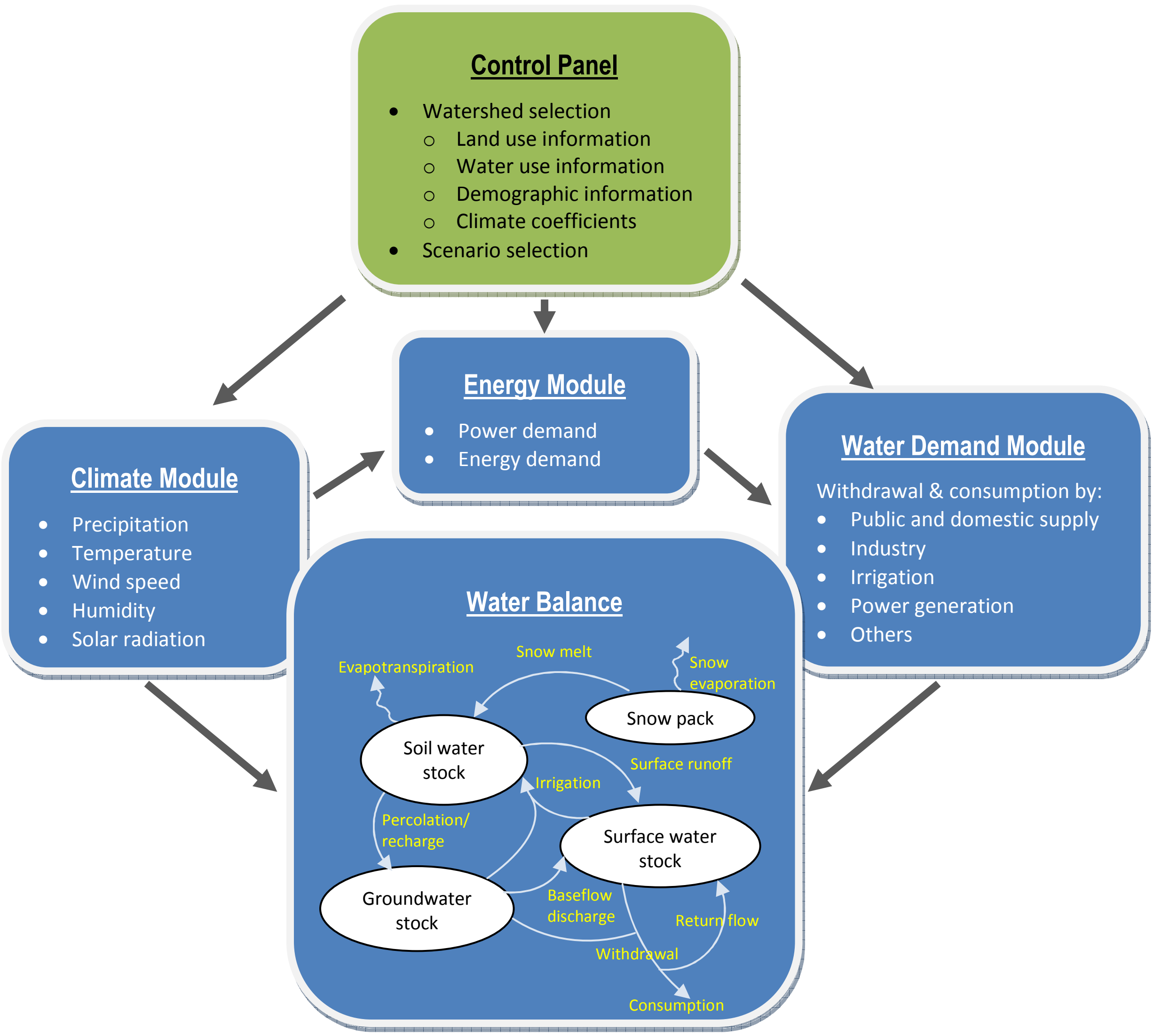


Figure 4.1 Architecture of the modeling framework. The system behavior is governed by the control panel (green block) and synchronized through the functional connections (gray arrows). Water stocks (blue blocks) and flows (blue arrows) then fluctuate accordingly in responding to the selection of target watersheds and scenario.

System dynamics modeling is a valuable tool for investigating complex systems with many interacting components, which change over time [41]. It has been used frequently since its development in the 1960's to conduct forecasts of natural resource systems for management and decision-making purposes [42-44].

4.2.1. Climate and water availability modules

When daily mean temperature is higher than 0 °C, precipitation flows into the soil compartment as rainfall (P_{RAIN}); otherwise, snow falls (P_{SNOW}) and accumulates as snow pack. Temperature patterns are established based on historical data coupled by Richardson's method [45]:

$$
\begin{aligned}
&T_t = \mu_T + \rho(T_{t-1} - \mu_T) + \varepsilon\sigma_T\sqrt{1-\rho^2} \\
&\mu_T = C_{0\mu_T} + C_{1\mu_T}\cos\left(\frac{i}{365/2\pi} + \theta_{\mu T}\right) \qquad \text{eq.4} \\
&\sigma_T = C_{0\sigma_T} + C_{1\sigma_T}\cos\left(\frac{i}{365/2\pi} + \theta_{\sigma_T}\right)
\end{aligned}
$$

where T_t represents T_{max} or T_{min} at time t, and is determined by its previous state (T_{t-1}), historical average at a given day of T_{max} or T_{min} (μ_T) and the standard deviation of each (σ_T). In eq. 4, coefficients C_0, C_1, and θ are estimated individually based on historical data, and the term ε is a randomly generated standard normal deviate.

Several other minor climate inputs are also required for further use in computing water flows of evapotranspiration and snow evaporation, including extraterrestrial radiation (R_a, MJ $m^{-2}day^{-1}$), wind speed (V_w, m sec^{-1}), and relative humidity (R_h , percent).

$$
\begin{aligned}
&R_a = \frac{118.08dr}{\pi}(\omega s \times \sin(LAT)\sin(\delta) + \cos(LAT)\sin(\omega s)) \\
&dr = 1 + 0.033\cos\left(\frac{2\pi}{365} \times t\right) \\
&\omega s = a\cos(-\tan(LAT)\tan(\delta)) \qquad \text{eq.5} \\
&\delta = 0.409\sin\left(\frac{2\pi}{365} \times t - 1.39\right) \\
&LAT = \frac{\pi}{180} \times \text{latitude of a watershed in decimal degree}
\end{aligned}
$$

where dr is the inverse relative distance between the sun and earth on the given day t, and ωs is the solar time angle defined by the sun's declination above the celestial equator (δ) and the latitude of a studied watershed in radians (LAT). To obtain wind speed and relative humidity (R_h , percent) values for each watershed over time, the same procedure previously introduced for computing temperature is applied again.

All these climate factors are then used to regulate hydrological flows in the water balance module, including evaporation, evapotranspiration, percolation, baseflow and runoff, in which the sum of percolation and runoff is employed to illustrate local water availability. To simulate the water balance in each compartment, a series of water stock and flow relationships were established based on linear-reservoir dynamics.

4.2.2. Water demand module

The water demand model in this study places water withdrawal (WU_T , m^3) and consumption (WC_T , m^3) in five categories, including industrial water (WU_{IND} , WC_{IND}), irrigation water (IRG), public supply (WU_{PB} , WC_{PB}), water for power generation (WU_E , WC_E) and other special usages (WU_{SP} , WC_{SP}). Except for power generation, the other four categories are computed based on the per-capita usage rate and climate characteristics of each watershed. Power generation water usage is estimated using state wide electricity demand. Thus, for some watersheds, the water extracted for power generation can be zero if there is no power plant in that watershed.

$$WU_T = \sum (IRG + WU_E + WU_{IND} + WU_{PB} + WU_{SP}) \quad \text{eq.6}$$

For each water demand category, a consumption and withdrawal ratio (r_{cw}) is determined based on literature review, and water demand is determined in the same fashion.

4.2.2.1. Industrial water

Industrial water demand relies heavily on economic and manufacturing activities, and often can be estimated together with domestic water demand as a function of population [46, 47]. However, industrial water withdrawal per person can vary widely from 0 m^3 per capita per year ($m^3 capita^{-1} yr^{-1}$) in some watersheds, such as the Nemadji River or Redeye River watersheds, to 27,196 $m^3 cap^{-1} yr^{-1}$ in the North Lake Superior watershed with an average of 825 and standard deviation of 4,152. Demand for public water supply varies much less, with an average rate of 170 $m^3cap^{-1}yr^{-1}$ and standard deviation of 502 [17]. Therefore, industrial water should be separated from public water use.

In addition, a watershed-based withdrawal rate is adopted to incorporate local climate characteristics instead of applying a state-averaged industrial withdrawal rate.

$$WU_{INDij} = PP_i \times cap_{INDij} \quad \text{eq.7}$$

where PP_i is the annually averaged population in watershed i, and cap_{INDij} is the watershed-explicit per capita industrial water withdrawal rate ($m^3captia^{-1}day^{-1}$) in day j of a year. Data indicate that the per-capita-basis industrial withdrawal rate is highly correlated with temperature. Therefore, the cap_{IND} value was adjusted based on annual industrial withdrawal rate ($avgcap_{IND}$, $m^3cap^{-1}yr^{-1}$) and maximum temperature ($T_{\max_{ij}}$, °C) to fit the climate- driven trend using the following equation, in which all the coefficients were derived from historical data:

$$cap_{INDij} = avgcap_{INDi} \times (1 + 0.1156 \times T_{\max ij}) \times 0.0012 \quad \text{eq.8}$$

4.2.2.2. Public and residential supply water

Public and residential supply water (WU_{PR}) is made up of public supply systems and self-supplied water from wells, and is highly regulated by seasonal climate patterns and population [48]. On an annual basis, data indicate that WU_{PR} may be estimated by using population information [17]. Data also show an increase in annual per-capita public and residential water supply from 1990 to 2007.

Temperature is the most significant factor regulating the fluctuation of daily WU_{PR} [49]. Therefore, daily WU_{PR} (m^3) of watershed i at day j can be computed by using the following equation:

$$\begin{aligned} WU_{PRij} &= PP_i \times cap_{PRij} \\ cap_{PRij} &= avgcap_{PRi} \times (1 + 0.1156 \times T_{\max ij}) \times 0.0012 \end{aligned} \quad \text{eq.9}$$

where cap_{PB} indicates daily per-capita withdrawal rate (m^{3}captia^{-1}day^{-1}) and $avgcap_{PRi}$ (m^{3}captia^{-1}yr^{-1}) is the per-capita annual WU_{PR} derived from historical data. Constant a is the coefficient of daily maximum temperature ($T_{\max ij}$, °C) and b is the coefficient for scaling. In this study, a and b were set to 0.1156 and 0.0012, respectively.

4.2.2.3. Irrigation water

Irrigation water demand associated with climate change in a large-scale study can be estimated based on changes in crop evapotranspiration, and is often expressed as the deficit between local rainfall and evapotranspiration [50-52].

$$IRG = \sum (P_{RAIN} - ET_{cropi}) \times f_{A-irg} \qquad \text{eq.10}$$

where IRG (mmday^{-1}) is the total irrigation water demand in a watershed, and is the sum of the water deficit of local rainfall (P_{RAIN}, mmday^{-1}) and the evapotranspiration of a certain crop i (ET_{cropi}, mmday^{-1}) times the fraction of area in a watershed where irrigation is applied (f_{A-irg}, percent). The fraction factor of irrigated area is taken into account in the study to overcome the difference in irrigation schedule resulting from crop growth and planting distribution. Both variables of rainfall and evapotranspiration of difference crops will be computed based on the method described in the water supply model, and f_{A-irg} can be compiled based on empirical data.

4.2.2.4. Water for power generation

In this study, it is assumed that power generation schemes will remain the same throughout the study period. Thus, the location of existing power plants will remain the same without geographical expansion and with no changes in fuel source, and water efficiency will remain stable across the studied period. Water for power generation is modeled using the change in state total population (PP_{MN}) and climate in this study. Water for power generation is represented as:

$$WU_{Ej} = (PP_{MN} \times cap_E) \times \sum (f_{fi} \times f_{Eij}) \qquad \text{eq.11}$$

where WU_{Ej} is the total water withdrawn (m^{3}day^{-1}) for power generation at a given watershed at day j for power fuel type i, cap_E is the daily power demand per capita (MWhr capita^{-1}day$^-$

[1]), f_{fi} is the fraction of fuel type i used in generating power at the given watershed, and f_{Eij} is the power generation seasonal weighting factor of fuel i at day j. The fuel types are categorized into four groups in the study, including steam power (thermal), hydropower, nuclear power, and others which are solar, wind, and other power generation technologies.

Integrating state population change from 1990 to 2007 with power generation data, the cap_E shows an increasing trend in the past two decades [53] and has been found highly correspondent with climate change, yet with significant regional variances [54, 55]. A prior study proposed estimating monthly power demand as a function of temperature [56, 57]. Minnesota's historical data also show evidence of electricity demand being leveled by seasonally fluctuating electricity retailer prices (EP). Therefore, to overcome regional differences and establish a numerical method to illustrate power demand dynamics specific to Minnesota , the following equation was derived from historical data (R^2=0.9) and adopted in estimating total power demand over time:

$$\begin{aligned} cap_E = & -3.95\times10^{-5}T_{\max} + 1.10\times10^{-3}T_{\min} + 3.49\times10^{-3}EP \\ & -1.16\times10^{-6}T_{\max}{}^2 + 3.90\times10^{-5}T_{\min}{}^2 - 2.60\times10^{-5}EP^2 - 8.38\times10^{-2} \end{aligned} \qquad \text{eq.12}$$

In this study, the seasonal fluctuation of electricity price (EP) is embedded in the model, but the annual average price remains constant over time. By employing this procedure to estimate power generation, the computed result showed high accuracy with only 0.1% error when compared with the official electricity demand data from 2000 [53].

4.2.2.5. Energy and refinery

The only refineries in Minnesota that consume significant water in producing energy fuels are ethanol plants and petroleum refineries. Historical data indicates that ethanol refineries derive water from both industrial and public supply systems, whereas petroleum refineries' water withdrawal is listed under the category of industrial water. Thus, in this study, energy water accounts for processing water acquired by ethanol and petroleum refineries. We assumed that processing one cubic meter of ethanol and petroleum requires 3.6 and 1.47 m^3 of water, respectively [58-61].

4.2.2.6. Special water withdrawal

This category of water withdrawal accounts for occasional usage including air conditioning, snow making, water level maintenance, or temporary withdrawal. This category only accounts for 0.42 % of state withdrawals on average. Therefore, it is treated as a fixed percentage of the total withdrawal from the other categories estimated based on each watershed's historical data.

4.2.2.7. Withdrawal, consumption and water sources

Due to the lack of consumptive water tracking, a set of conversion factors (r_{cw}) to estimate consumptive water from withdrawal by different water demand categories is employed in this study. For industrial consumption, a prior study states that industrial water shows relatively similar reuse ratios in the U.S. among different industries, and ranks from 53.9% to 74.5% [62]. Therefore, a rational withdrawal and consumption ratio is randomly selected from a normal distribution with an average of 63% and standard deviation of 3%. For consumptive public supply and irrigation, r_{cw} values of 86% and 73% of total withdrawal in each category is applied [63, 64], whereas consumptive water volume is set to equal the total withdrawal for the special demand category.

However, the estimation of power water consumption is more complicated due to the wide variance of cooling methods. For instance, water loss can range between 0.26% to 91.6% from an open-loop cooling system to a wet-tower cooling one [10]. To overcome the difference, a set of fuel-type weighted conversion factors taking cooling system types into account is calculated and applied to individual watersheds based on the electrical plant types located in that watershed. The conversion factors remain consistent over time because, as previously mentioned, the fraction of each driver fuel contributing to total power generation is assumed to be the same as in years 2000 to 2008.

Within each watershed, humans derive water from water stock either stored in surface reservoirs or in aquifers. The ratios of withdrawal from surface water and groundwater are explicitly calculated watershed by watershed for each water demand category. The ratio of surface water and groundwater extraction in supporting a demand category of a watershed is assumed to remain consistent over time.

4.3. Indicators

This study used water withdrawal, water consumption, and water stress index (water withdrawal as a proportion of total available water) as indicators for interpreting water resource status under different climate and energy scenarios. The total available water accounts for the surface runoff and groundwater recharge before anthropogenic withdrawal takes place. It is important to realize that this maximum water availability does not imply the maximum allowance for anthropogenic usage, and a certain fraction of water should remain available for ensuring ecological integrity.

Both water withdrawal and consumption are in cubic meters. Water stress index, on the other hand, is dimensionless and normally falls in between 0 to 1. However, in some populated areas, the water stress index may be greater than 1 indicating that withdrawal patterns exceed what the system can naturally supply. The water stress index values of 0.1, 0.2 and 0.4 are the thresholds of low, mid-high, and severe water stress, respectively [30, 65]. Each indicator was computed on a daily basis within a watershed, but may be aggregated monthly for presentation purposes.

5. Development of scenarios

This study focused on a series of scenarios related to potential changes in corn-based bioethanol production, population, electricity demand, and climate. In establishing each scenario, we derived projections based on cases relevant to Minnesota's social and economic background, energy policies.

5.1. Increase of biofuel production

According to the Annual Energy Outlook 2007 reference case published by the U.S. Energy Information Administration, ethanol was projected to account for 7.6% of the total gasoline consumption by 2030, in which the latter was projected to increase by 34% from 2007 to 2030 on a volume basis [66]. This can be translated into a total ethanol demand of 41.2 million m^3 by 2030. Therefore, we developed Minnesota's ethanol business-as-usual scenarios by 2030 using the national figures of 41.2 million m^3, and assumed Minnesota would produce 10% of the national ethanol pool, as was the case in 2007 [21, 67]. To create the extreme ethanol scenario, we assumed 20% more production compared with this base case.

5.2. Increase of population

The State Demographer has population projections published up to the year 2035 by county [9]. The state demographer estimates a population of 6,297,300 in 2030, which was selected to be the business-as-usual scenario in this study. To develop the extreme scenario, an additional 20% of the business-as-usual population figure was used.

5.3. Electricity use

The business-as-usual power scenario derived from historical data (denoted as Power(N)), assumes that power demand per person would reach 17.3 MWh by 2030[53, 68]. The extreme case, or Power(X) scenario, assumed 20% additional increase in power demand per person, which would lead to 20.76 MWhr per person by 2030.

5.4. Climate change

To generate climate scenarios, data were generated and downloaded from exogenous sources developed by the U.S. Bureau of Reclamation Technical Service Center, Santa Clara University, and the Lawrence Livermore National Laboratory [69]. Various global climate models and emission scenarios are available for downscaling through this data site, and we have chosen one of them that represents the case of extreme use of energy (IPCC A2 emission scenario) [69] Climate under business-as-usual was set to stay the same as the normal climate patterns of 2000s. Climate data for the extreme climate change scenario (2030CE scenario in this report) were acquired from MRI CGCM (2-3-2A).

The combination of assumptions under each scenario is summarized in Table 5.1.

Table 5.1 Summary of scenarios tested in this study.

Scenario	Description of assumption				
	Description	Climate	Population	Ethanol	Power
BL	Baseline case in year 2000	—	—	—	—
CnBAU	Business-as-usual scenario by 2030	—	N	N	N
CxBAU	Business-as-usual plus climate change scenario by 2030	X	N	N	N
Cx	Climate scenario by 2030	X	—	—	—
PPn	Population scenario by 2030	—	N	—	—
EtOHn	Ethanol production scenario by 2030	—	—	N	—
PWn	Power generation scenario by 2030	—	—	—	N
Extreme	Extreme scenario by 2030	X	X	X	X

—: current average status in 2000s

N: business-as-usual scenario
X: extreme scenario

6. Results

We grouped individual watersheds into 9 zones based on Minnesota's climate divisions defined by NOAA (Figure 3.4). On the temporal scale, study results were presented per monthly spans in order to highlight seasonal variations. Because the study is aiming to illustrate how Minnesota's water resources would respond to different scenarios, it is important to highlight the magnitude of water flow change departing from the baseline.

The results show that as a result of climate change, western Minnesota continues to be more arid than the eastern part of the state. However, the amount of water available, which is defined as precipitation minus run-off, is expected to increase more significantly in the west (34%~70%) than in the east (-2%~18%) under climate change effects by year 2030 (Table 6.1).

Population change is expected to increase water withdrawal in almost every category, except for the irrigated water category that responds primarily to climate change (Figure 6.1).

In general, water withdrawal increases significantly under the extreme scenario (Extreme) as expected, in which population change played the most important role in driving future water withdrawals. Electricity demand could also considerably amplify water withdrawal in the locations where power plants are currently located. The effects caused by increasing ethanol production became marginal as compared with the changes induced by population and power generation increase. Climate change, on the other hand, contributed trivial impacts on water withdrawal compared with the forces of population and energy in the short term. However, water withdrawal would still peak during summer in every region while the relative magnitude of increase in withdrawals compared to water availability would be more significant during the winter. In contrast, available water would increase notably in spring but decrease in summer.

Unlike water withdrawal, water availability is governed mainly by climate in all regions, except for the Mississippi River watershed (No. 20), where its anthropogenic withdrawals could already be influential enough to alter the local water hydrograph. Using water stress index (WSI, total water withdrawal/total available water) as an indicator, there were eight watersheds classified as high water stress (WSI>0.2) during 2000s, which would increase to 12 watersheds under the extreme scenario by 2030.

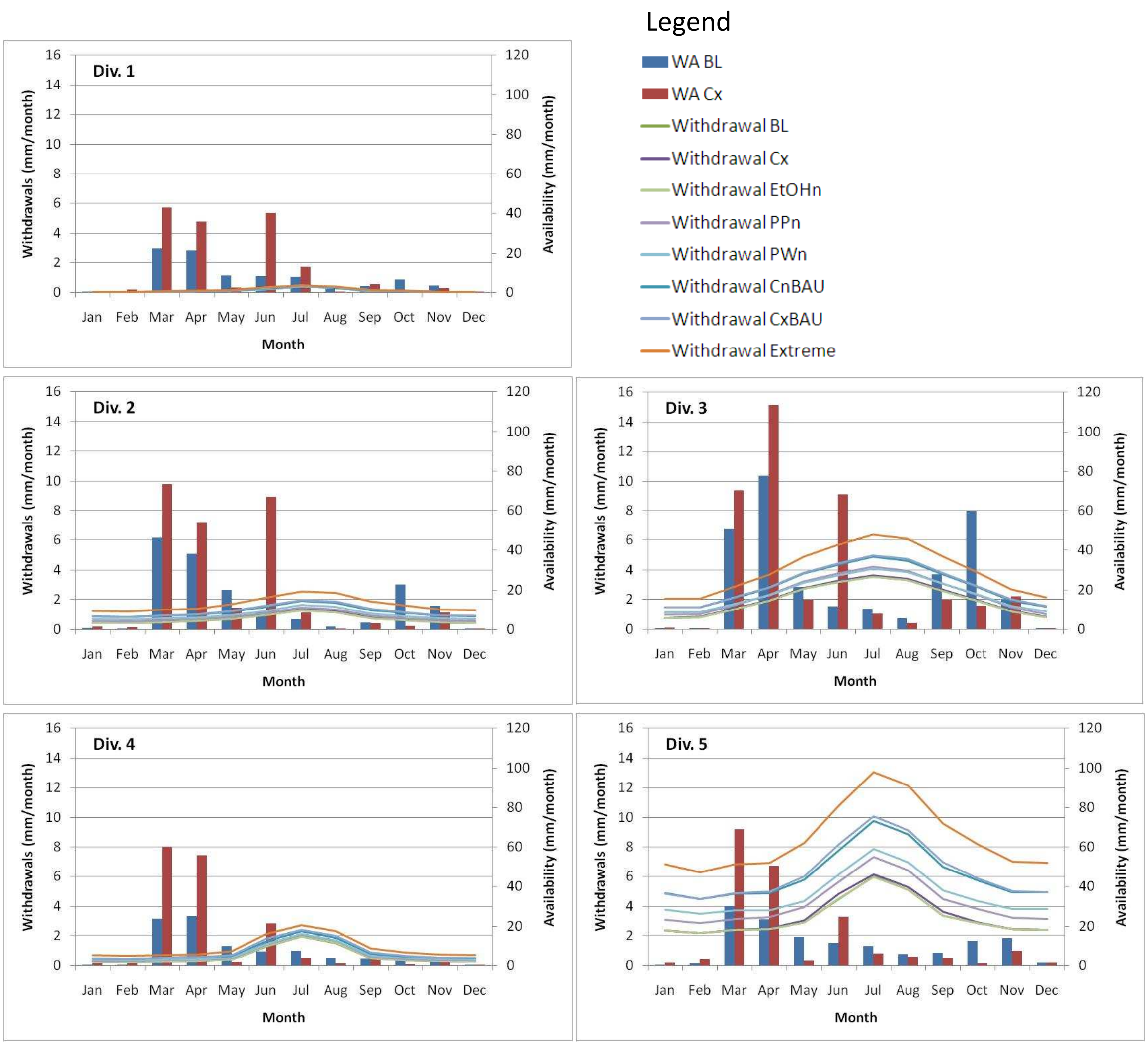
If each driver of change is tested separately, population change and change in electric power grid-mix can elevate state average WSI from 0.14 up to 0.18 and 0.19, respectively. On the other hand, climate can slightly lower WSI down to 0.11. Table 6.2 provides a snapshot indicating which areas might be more vulnerable under demographic and power demand change in the future.

Table 6.1 Water availability, withdrawal, and consumption under different scenarios. BL = Baseline case in year 2000; Cx = Climate scenario by 2030; PPn = Population scenario by 2030; PWn = Power generation scenario by 2030; EtOHn = Ethanol production scenario by 2030; CnBAU = Business-as-usual scenario by 2030; CxBAU = Business-as-usual plus climate change scenario by 2030; and Extreme = Extreme scenario by 2030.

Water Availability (mm/month)								
Division	BL	Cx	PPn	PWn	EtOHn	CnBAU	CxBAU	Extreme
1	84	144	81	81	82	84	139	136
2	161	231	161	162	161	161	229	228
3	280	323	273	276	276	276	320	317
4	91	154	84	89	88	90	150	147
5	132	175	127	126	128	130	174	170
6	218	257	213	216	214	215	255	251
7	92	124	91	91	91	91	125	125
8	145	163	140	150	147	151	156	157
9	191	187	186	190	188	191	186	185

Consumption (mm/month)								
Division	BL	Cx	PPn	PWn	EtOHn	CnBAU	CxBAU	Extreme
1	1	1	1	1	1	1	1	2
2	4	4	5	6	4	7	7	9
3	15	16	18	17	15	21	21	27
4	3	4	4	4	4	5	5	6
5	20	21	26	28	20	36	37	49
6	18	18	23	24	18	30	31	41
7	1	1	1	1	1	1	1	2
8	13	13	18	17	13	23	23	30
9	28	28	36	41	28	52	53	73

Withdrawals (mm/month)								
Division	BL	Cx	PPn	PWn	EtOHn	CnBAU	CxBAU	Extreme
1	1	2	2	1	1	2	2	2
2	8	9	10	12	8	14	15	20
3	24	25	29	29	24	36	36	47
4	8	8	9	9	8	11	12	14
5	39	40	50	57	39	74	75	103
6	45	46	57	63	45	79	81	110
7	4	4	5	5	4	7	7	9
8	24	24	32	33	24	44	45	60
9	51	52	66	78	51	100	102	142



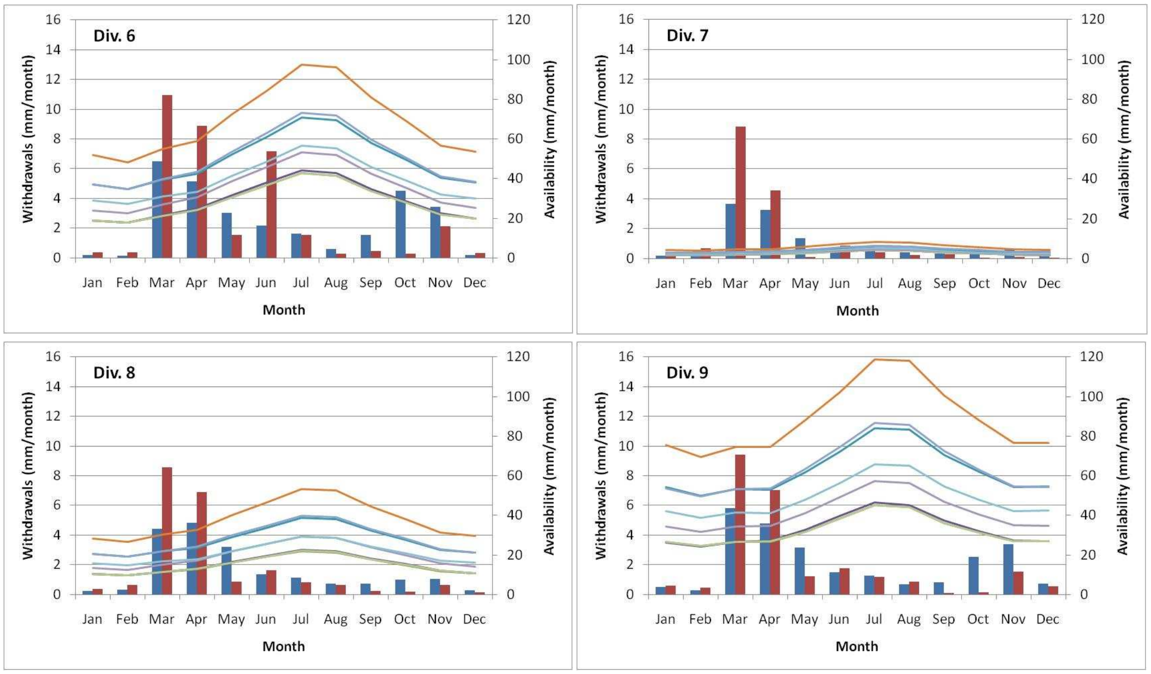


Figure 6.1 Water demand and supply under different scenarios by geographic division over time. Each region responds to the designated scenarios differently while sharing common seasonal trends.

Table 6.2 Water stress index under different scenarios. Climate change scenario may reduce WSI primarily due to the increase in available water. During summer time, excessive water withdrawals would outpace the increase of available water and result to severe water stress under the climate change scenario. Notably, many divisions are under water stress during summer time, which would be worsened under every scenario.

Scenario	BL	Cx	PPn	EtOHn	PWn	CxBAU	CnBAU	Extreme
Watershed Count	8	6	9	9	10	9	11	12
Annual Average WSI	0.14	0.11	0.18	0.14	0.19	0.19	0.24	0.27
Division	Average Summer (June – August) WSI by Scenario by Division							
1	0.06	0.27	0.07	0.06	0.06	0.27	0.06	0.30
2	0.39	1.17	0.45	0.39	0.49	1.79	0.59	2.32
3	0.41	0.54	0.54	0.44	0.51	0.79	0.61	1.04
4	0.28	0.75	0.32	0.30	0.31	0.94	0.34	1.06
5	0.63	0.80	0.77	0.63	0.84	1.40	1.05	1.87
6	0.65	1.15	0.86	0.68	0.87	1.99	1.14	2.72
7	0.12	0.19	0.13	0.12	0.15	0.29	0.18	0.38
8	0.37	0.43	0.50	0.37	0.46	0.84	0.62	1.11
9	0.73	0.67	0.95	0.74	1.09	1.30	1.36	1.83

*Red colored numbers indicate WSI > 0.5

The results also show that the amount of water withdrawals in Divisions 5, 6, and 9 is already approaching the amount of water available in those Divisions during the winter and summer months, and all scenarios except for Cx (extreme climate change only) exacerbate the situation considerably. In other words, these divisions represent the most likely regions where significant water stress (WSI of near 1 or even over 1) may be reached temporarily during the winter and summer months, indicating absolute shortage of renewable water during those periods. During these months, freshwater or groundwater stocks will have to be drawn down to supply regional water needs.

6.1. The case of increased biofuel production

Biofuel production is the least influential driver of the state's future water withdrawal and water stress. Under ethanol production scenarios, we assumed that ethanol refineries acquire 100% of corn feedstock from locally grown corn. This would require 7.3 million m^3 of irrigation water under the EtOHn scenario, and 10.6 million m^3 under the Extreme scenario. These represent an increase of 38% and 101%, respectively, in ethanol-appropriated irrigation compared with the BL scenario. Combining irrigation and process water, the ethanol industry would withdraw 22.1 million m^3 or consume 20.4 million m^3 of water a year under the EtOHn scenario (Figure 6.2). This scenario assumed that ethanol would be produced in existing and currently proposed facilities, and that corn would be sourced from the same regions from which it is currently. We found that, in order to satisfy the ethanol production under both EtOHn and Extreme scenarios, approximately 34% and 41% of state corn production would be acquired by the ethanol industry if both yield rate and planted acreage remain the same into the future.

With this site-specific assessment, we also found that the total water withdrawal needed to produce ethanol spans from 3 m^3 water/m^3 ethanol to 19 m^3 water/m^3 ethanol with an average of 5.4, which is lower than the previous state-level estimation of 19 [4] or national average of 263 to 784 m^3 water/m^3 ethanol [23, 70, 71]. The average figure would increase slightly to 6.3 m^3 water/m^3 ethanol in the future due to the proportional increase of appropriating corn from irrigation-fed areas.

Though ethanol production is less likely to deplete Minnesota's overall water resources than population growth or electricity demand [4], it can induce local water stress. The bottom-right map in Figure 6.2 highlights potential water stress corresponding to ethanol plant location and local water availability under the Extreme scenario. As shown in the lower right figure, higher stress would be expected around the southern region of Minnesota if current production expansions continue. In some areas in the southern region, extreme ethanol production is expected to require up to about 4% of the available water in the region (Fig. 6.2 bottom right).

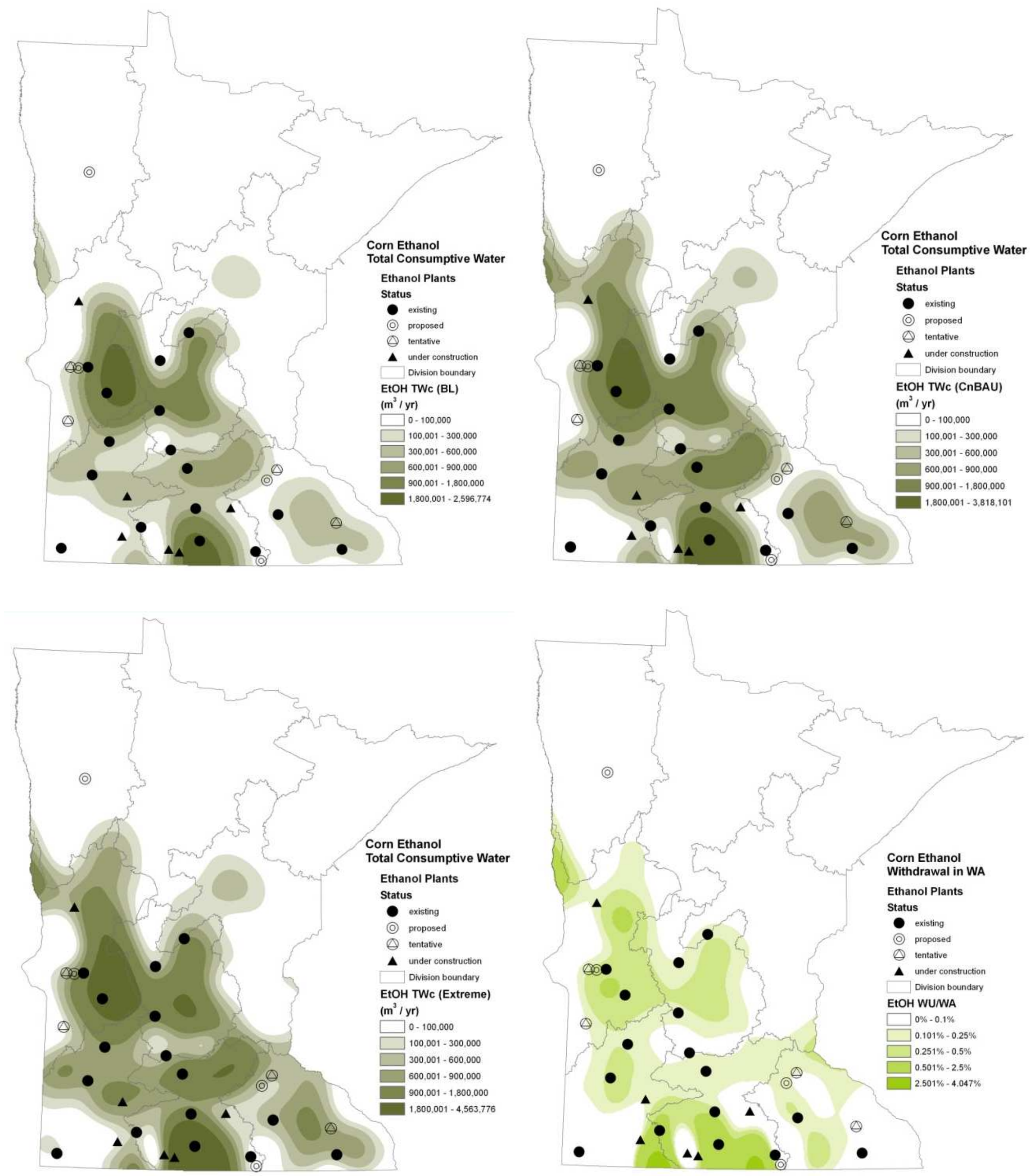


Figure 6.2 Total consumptive water (TWc) in ethanol under three production scenarios: 2000 baseline (BL), 2030 business-as-usual (CnBAU), and 2030 extreme (Extreme). TWc accounts for both process water and irrigated water in ethanol. The bottom-right map shows the total ethanol withdrawal in total available water.

6.2. The case of increased electricity demand

Water withdrawal in each Division for power generation ranges from 26 thousand m^3 (Division 1) to 815 million m^3 (Division 6), with an average of 309 million m^3 in 2000 – 2009. Under the PWn scenario, the power industry would withdraw 61% more water than under the BL scenario. Due to the various capacities and fuel sources of power plants by region, extreme water demand would be observed in the upper-central and east-central areas of Minnesota (Figure 6.3, left).

The difference between withdrawal and consumption implies different regions may respond to water shortage differently (Figure 6.4, right). For instance, if a drought occurs, Division 6 and 9 may experience difficulties in meeting electric power demand due to the lack of sufficient water supply. In the long term, water balance in Division 6 and 9 could be significantly altered due to the considerable portion of water withdrawn by power industries in these regions.

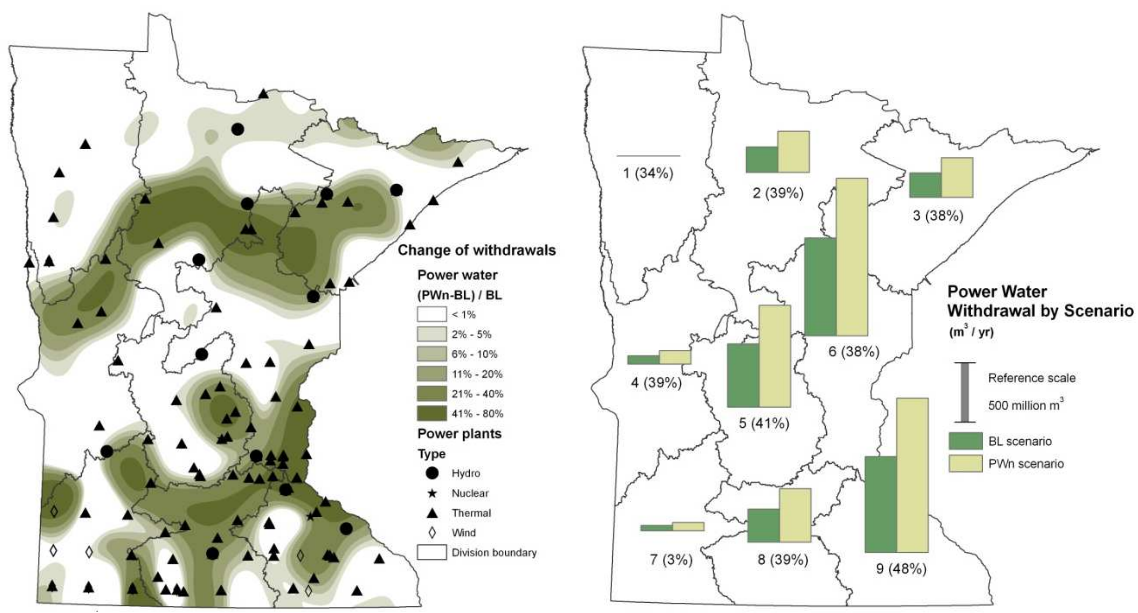


Figure 6.3 Change of water withdrawal under PWn scenarios as compared to that under BL (left). The percentages shown on the map (right) indicate the share of water withdrawn by power plants as a fraction of total available water in each division.

6.3. The case of increased population

The results show that population change can be the most powerful driving force in altering water withdrawal volume and affecting multiple usage categories. Changes in population can elevate not only water withdrawal by public supply systems, but also increase power demand which also has a positive feedback on amplifying water withdrawals. Due to the historical positive correlation between population change and industrial water use, the change of population also implies increased consumption of water classified for industrial supply.

Therefore, under the population growth scenario (PPn), the state would withdraw 5.9 billion m^3 of water in order to support the communities and economic activities associated with this population growth, which would amount to 3.2 billion m^3 of water consumption. This would add an additional 1.2 billion m^3 of water withdrawal from what was needed under the BL scenario. On average, water withdrawals for industrial, public, and power usage would range from 23% to 28% under the sole effect of population growth.

The increase would primarily affect those regions with significant population growth or where power plant density is higher (Figure 6.4). As Minnesota's cities and population sprawl from the south-east region toward the north-east corner of the state, water demand shows asimilar pattern.

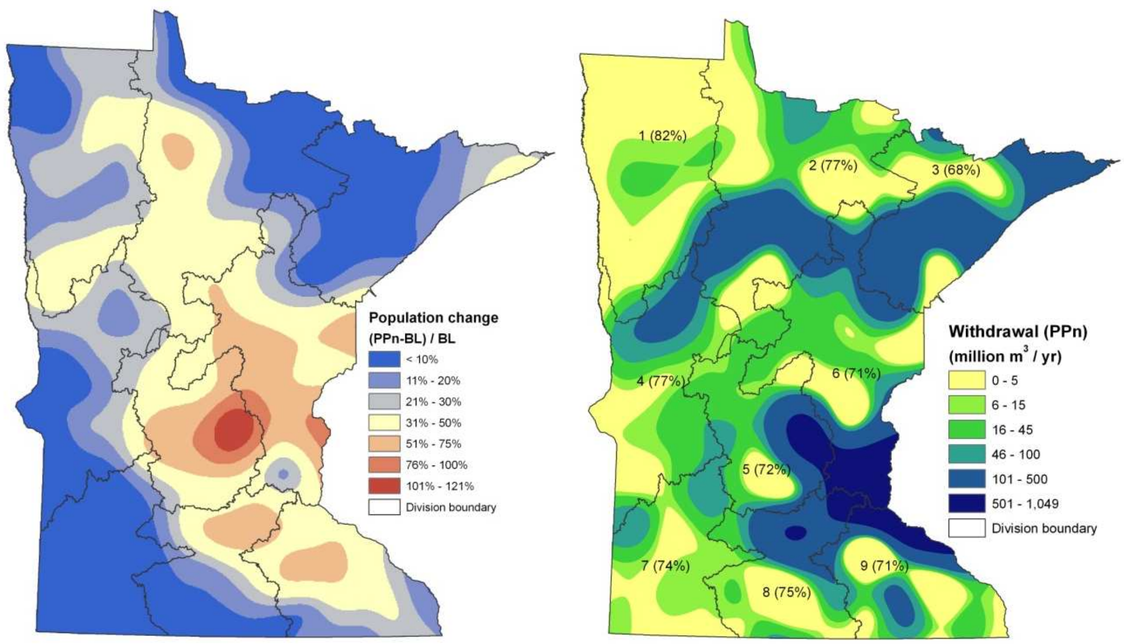


Figure 6.4 Total water withdrawal under the sole effect of population growth (PPn, right) and its spatial correlation with population change magnitude by 2030 from 2000 (left). Numbers in parentheses represent the percentage of consumptive water in withdrawal.

As shown previously in Table 6.2, water withdrawals for industrial, public supply, and power generation usage driven by population growth could create uneven water stress in different regions in the state. Though most of the "hot-spot" regions currently receive more precipitation than the rest of the state, the ratio between withdrawal and availability may soon reach parity if water use patterns remain unchanged.

6.4. The case of climate change

Climate change ranks third in affecting total water consumption following population and power demand. Even considering the short time span of this modeling effort, climate change impacts on Minnesota’s water resources can be seen within the next 20 years. This implies climate change should be taken into account not only for making long-term but also short-term policies on sustaining water resources.

The climate scenario (Cx) would substantially increase irrigation needs by 5% to 18% with an average of 11% above what Minnesota currently applies. Though the climate effects on other usage categories would be relatively marginal compared with the effects on irrigation, industrial and public water withdrawals could increase by 8%, public supply by 4% and power generation water by 1% (Figure 6.5). Though the climate scenario may increase water availability in all divisions (except for Division 9) by 14% to 67% from BL, the increase in water withdrawals driven by the growth of population and energy by 2030 would still outpace the net gain of available water volume from climate change and result in an increase in water stress.

In terms of increasing irrigation demand, the central part of Minnesota, where irrigation rates are currently higher than in the rest of the state, would be the primary region affected by this scenario. Areas with higher increases in irrigation, however, would be located in the north due to the relatively significant increases in evapotranspiration in these regions.

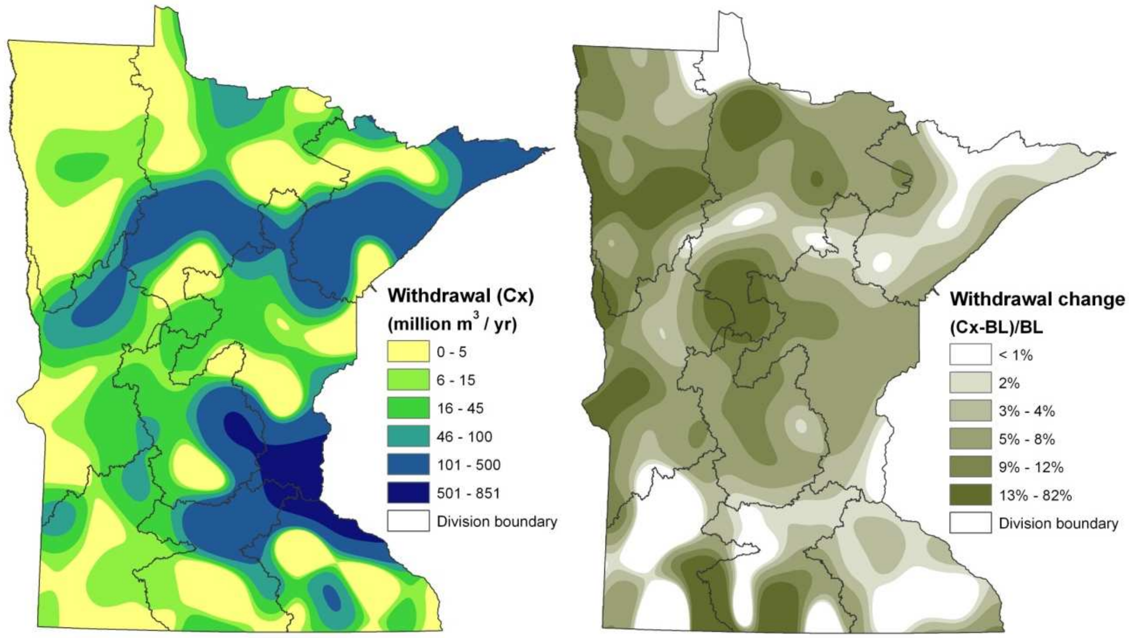


Figure 6.5 Total withdrawals under climate scenario (left) and proportional increase above BL scenario (right).

6.5. Extreme scenario

Under the extreme scenario, in which Minnesota would reach the highest population, energy consumption, and ethanol production growth under climate change effects, water withdrawal would increase to around 141% above BL levels by 2030. During the same time, water consumption is expected to increase to around 120% of the 2000 level. By then, Minnesota is expected to withdraw 11 billion m^3 of water which accounts for 27% of what is available, and nearly 50% of withdrawals would be consumed. Spatially, eastern and upper-central Minnesota would experience substantial increases in water withdrawal compared with the 2000s (Figure 6.6).

By use categories, water withdrawn to support power generation would increase the most (196%) followed by public and domestic supply (63%) (Table 6.3). Particularly, water used for energy-related industries would surpass any other industries proportionally in terms of growth rate. For example, an average of 1.9% of irrigated water, 0.4% of industrial water, and 0.7% of public supply water was attributed to the ethanol production sector during the 2000s. By 2030, these fractions would rise to 3.4%, 0.6%, and 0.9%, respectively. Together with traditional oil refineries, fuel industries would be responsible for nearly 3% of industrial water withdrawal. Though the fraction might not be significant compared with total water use, ethanol water demand would increase by 116% from 2000s to 2030, and oil refineries' water demand would grow 67%; whereas other industries would raise their water demand by 46% under the same scenario.

Under the extreme scenario, while the total water withdrawal would increase by 141%, water availability would only increase by 26% during the same period of time, resulting in a substantial increase in water stress from 0.14 to 0.27 (Figure 6.7). Compared to the current global average water stress of 0.1 [34], this implies that human activities in Minnesota are likely to surpass what the system could sustainably support if no strict actions will be taken in the future.

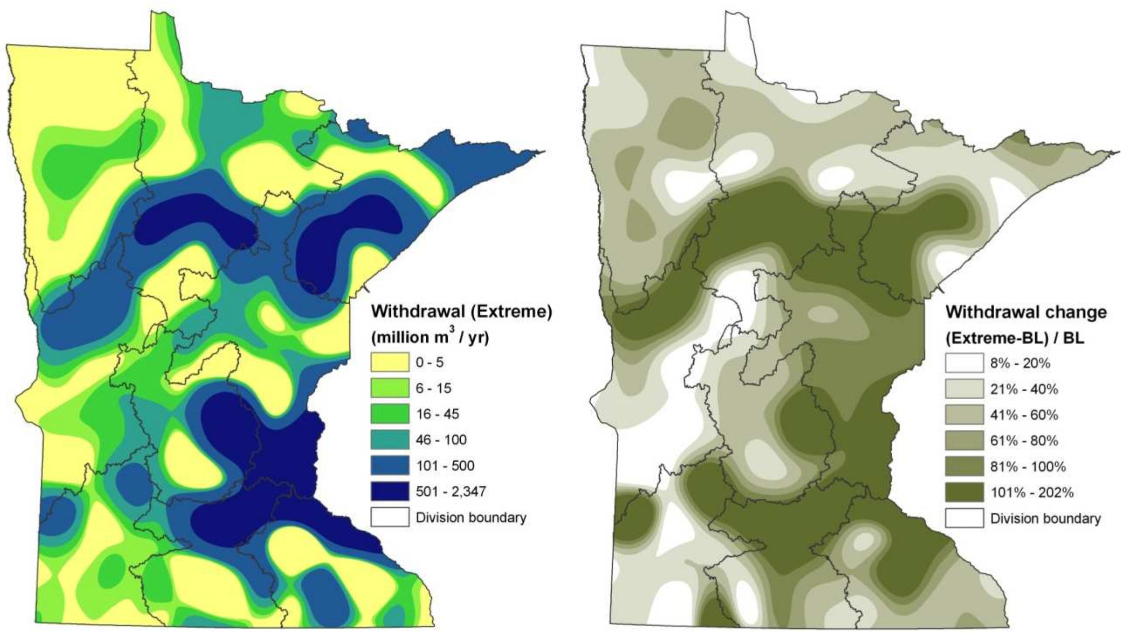


Figure 6.6 Total water withdrawal under the Extreme scenario by 2030 (left). Significant increase in withdrawal would occur in areas with high population growth (left) [72].

Table 6.3 Summary of water withdrawal by different user categories.

User category	Withdrawal (million m^3/yr)		Change
	2000 Baseline scenario	2030 Extreme scenario	%
Total irrigation	275	308	12%
Irrigation for ethanol	5	11	101%
Irrigation for other crops	270	297	10%
Total industrial water	479	706	47%
Ethanol process water	2	5	116%
Petroleum water	10	17	67%
Other industry	467	684	46%
Total Public & Domestic supply	855	1,390	63%
Ethanol process water	6	13	1%
Other users	848	1377	62%
Total water for power generation	2,946	8,720	196%
Other water withdrawal	168	256	53%
Total withdrawal (A)	4,724	11,379	141%
Total available water (B)	*34,114*	*42,837*	*26%*
Water stress index (A/B)	*0.14*	*0.27*	*93%*

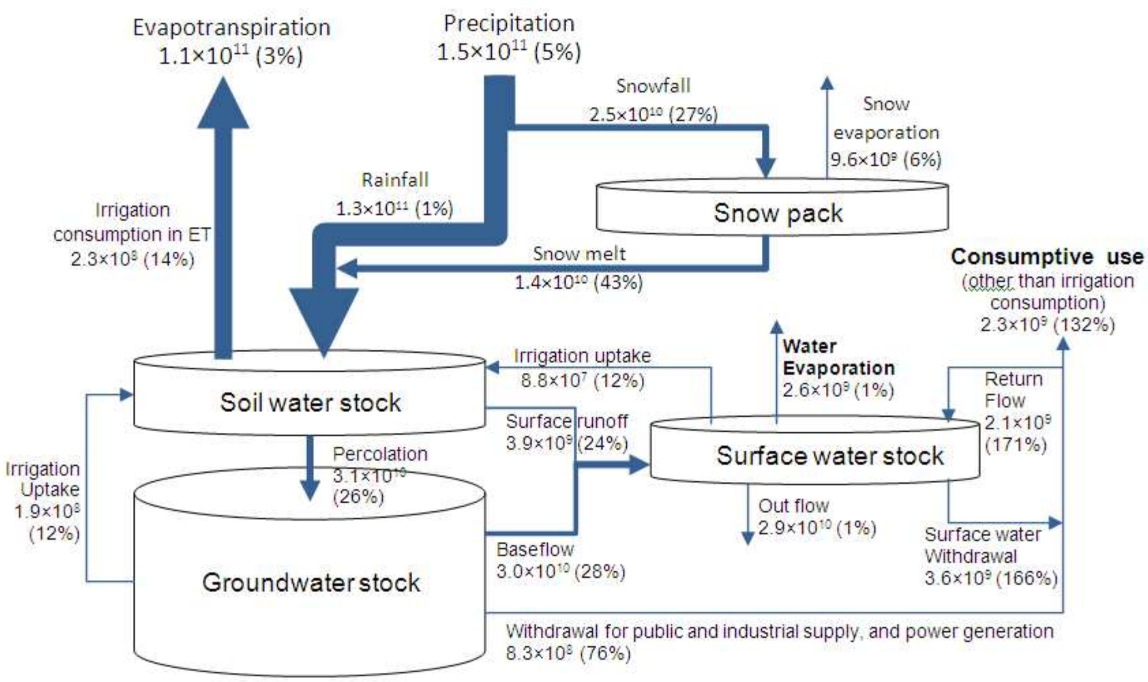


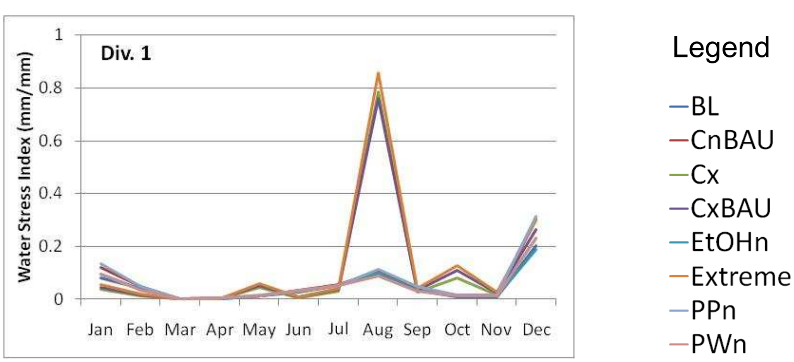
Figure 6.7 Snapshot of overall water balance under normal conditions (in m^3/yr) and flow change percentage from BL to Extreme scenario (in brackets). Figures may not add up due to rounding.

6.6. Seasonal water stress

Previous studies adopted the water stress index (WSI) to represent regional variation in potential water shortage under different combinations of water withdrawal and availability [30, 73]. It is also important to picture the seasonal dynamics of water demand and supply. The results from this study indicate that water stress mostly occurs between August and October, with regional variation (Figure 6.8). A cross examination showed that the stress taking place in August is normally driven by water withdrawal, whereas that in fall and winter results from low water availability. Though in most divisions, the Extreme scenario would significantly exacerbate water stress. The CnBAU scenario also showed that following current growth and consumption patterns could put Minnesota in potential water stress in winter time by 2030. Population growth would have the tendency to hasten the appearance of water stress, particularly in winter time. The climate scenario had a similar effect of worsening water stress as did population growth in the central and south regions of Minnesota, primarily in summer time.

During fall and winter time, the southern region might encounter relatively high water stress due to the low water supply coupled with higher water demand than the northern areas. Benefiting from the development of water allocation infrastructures and buffering functions provided by natural hydrological systems, the public may not physically experience water shortage in summers and winters unless a severe drought occurs. However, it is clear that Minnesota becomes especially vulnerable to unexpected water shortages during these periods of high WSI.

Populated regions including Division 5 and 6, in particular, extract over 100% of the water supplied by natural systems over 1/3 of the year under every scenario and over 3/4 of the year under the Extreme scenario. The results indicate that we are highly dependent on the buffering function or freshwater stock during these periods, or else we would experience drought.



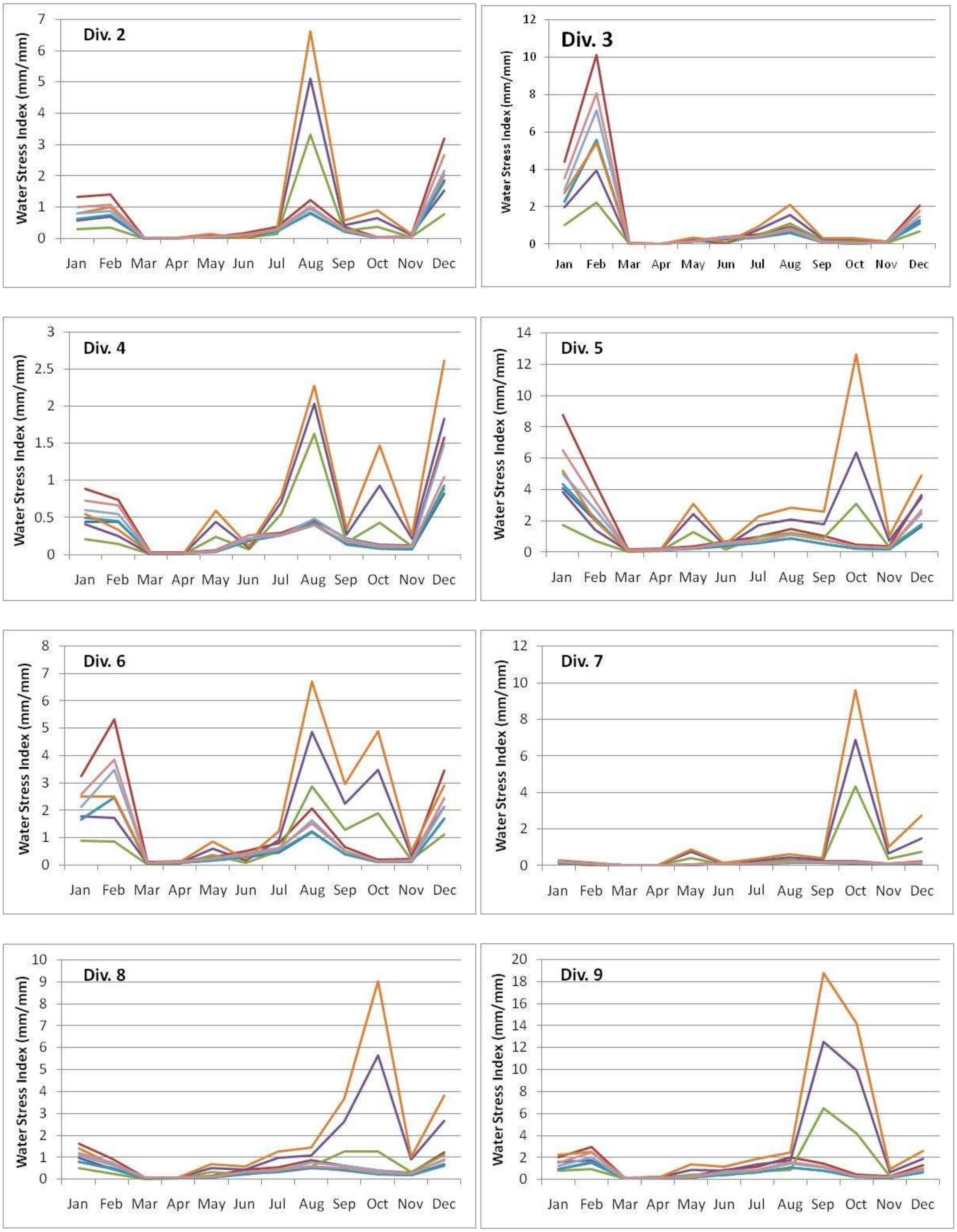


Figure 6.8 Water stress index over time in different divisions under designated scenarios.

7. Implications for sustainability

By coupling water demand and supply with system dynamics and GIS modeling tools, this study analyzed how Minnesota's water regimes might respond to various scenarios of population, energy, and climate change. Instead of identifying the absolute amount of water we have "in stock," this study forecasts the quantifiable relationships between water resources, social, and climate factors. This approach connects major drivers of change and their potential consequences in terms of water stress with explicit temporal and spatial dimensions, which allows us to envisage potential futures of the state's water environment.

Without a holistic analysis connecting various parts of the water supply-demand network together, water planning and policy may rely on anecdotal evidence, which is highly dependent on context. For instance, bioethanol's water use has been publicized in recent years, raising concerns about its implications for future water resources. Nevertheless, the results of the current study show that the ambitious target set by the ethanol blending mandate imposes a relatively small burden on the State's water environment, whereas population growth and increase in electricity consumption have the potential to significantly increase water stress in the future. In particular, Minnesota is expected to become significantly more vulnerable to late summer and late winter drought under the population and energy scenarios examined in this study.

Climate change is expected to supply more water to the State through increase in precipitation. However, the magnitude of increase in water availability due to climate change is relatively small as compared to the amount of water consumption increase under the population and energy scenarios. Moreover, most of the increase in precipitation due to climate change is realized during early spring, when flooding instead of drought has been the problem in Minnesota. Our model used a monthly time-step, while accurate characterization of climate change impacts on water availability may require daily or even hourly time-steps in order to take the precipitation intensification impact on run-off into account.

The results highlight the importance of recognizing the connections between energy, population and water use in planning Minnesota's water future. Aligning urban and energy planning activities with water planning will be essential to avoid potential water shortage in the future. Conserving electrical energy, improving electrical energy efficiency and increasing the share of wind and solar power in the State's grid-mix are recognized as important considerations in reducing future water demand. On the other hand, potential increase in electricity demand without substantially increasing wind and solar power portion in the State's grid-mix will also increase future water demand. For instance, replacing internal combustion engine-powered vehicles by plug-in battery electric vehicles may substantially increase the State's water demand in the future.

The results also show that urban planning—especially in Divisions 5, 6, 8 and 9—should take potential water limitations into account. In doing so, considering the seasonality of water availability is critical. Using annual water balances for urban planning may seriously underestimate seasonal water shortage potential in later summer and winter.

8. Limitations of the model framework

The results and the conclusions drawn in this report cannot be generalized to other states, because all the parameters, models and scenarios are drawn for the case of Minnesota. For instance, Minnesota uses very little irrigation water for biomass feedstock production, and therefore, an increase in biofuel production has relatively small impact on water consumption. Ethanol production may induce significant change in water regimes in states that are relying on irrigation water for ethanol feedstock production.

The model framework built in this report is not meant to simulate physical water routing under storm events, but to quantify the magnitude of water demand and supply in various future scenarios. Though water regimes can be highly sensitive to additional changes associated with anthropogenic activities, some of the driving variables were assumed consistent. For example, under the population scenario, certain land use change is expected, while we did not take the land use change effect into account. When modeling climate change, only precipitation and temperature were altered leaving other factors including rainfall patterns and intensity as constants.

The current study took only water quantity into account. Future studies may take water quality and sensitivity of local ecosystems on water availability into account, to more fully measure the impacts of human activities on water resources.

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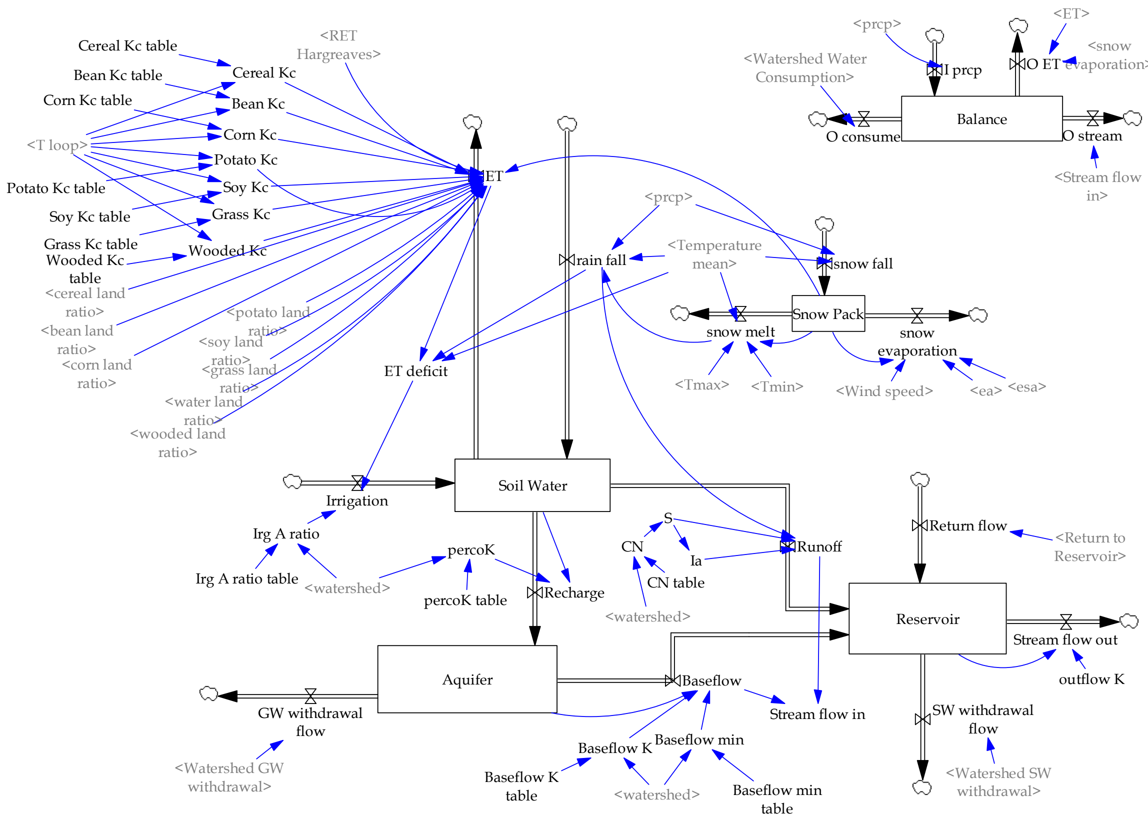
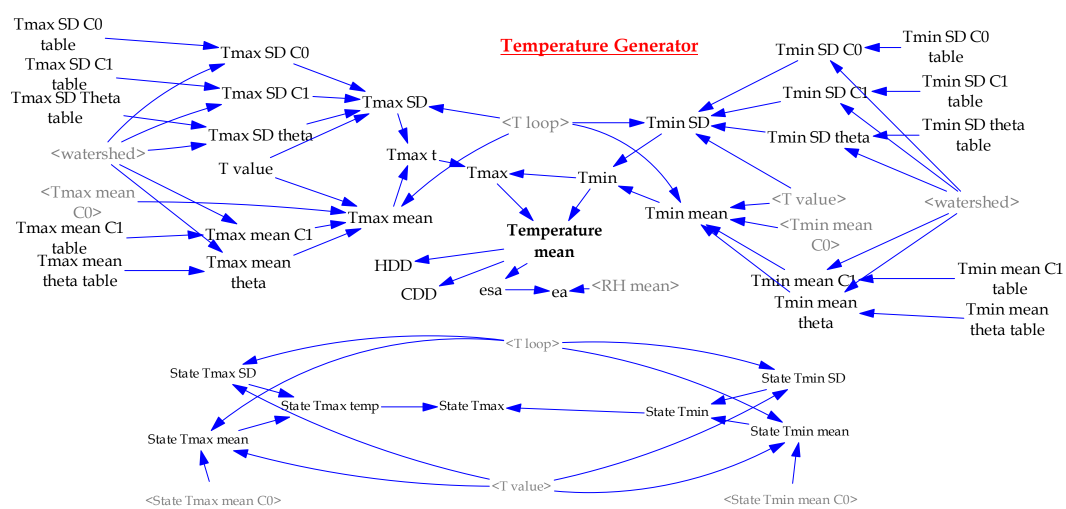
Appendix I – System dynamic model

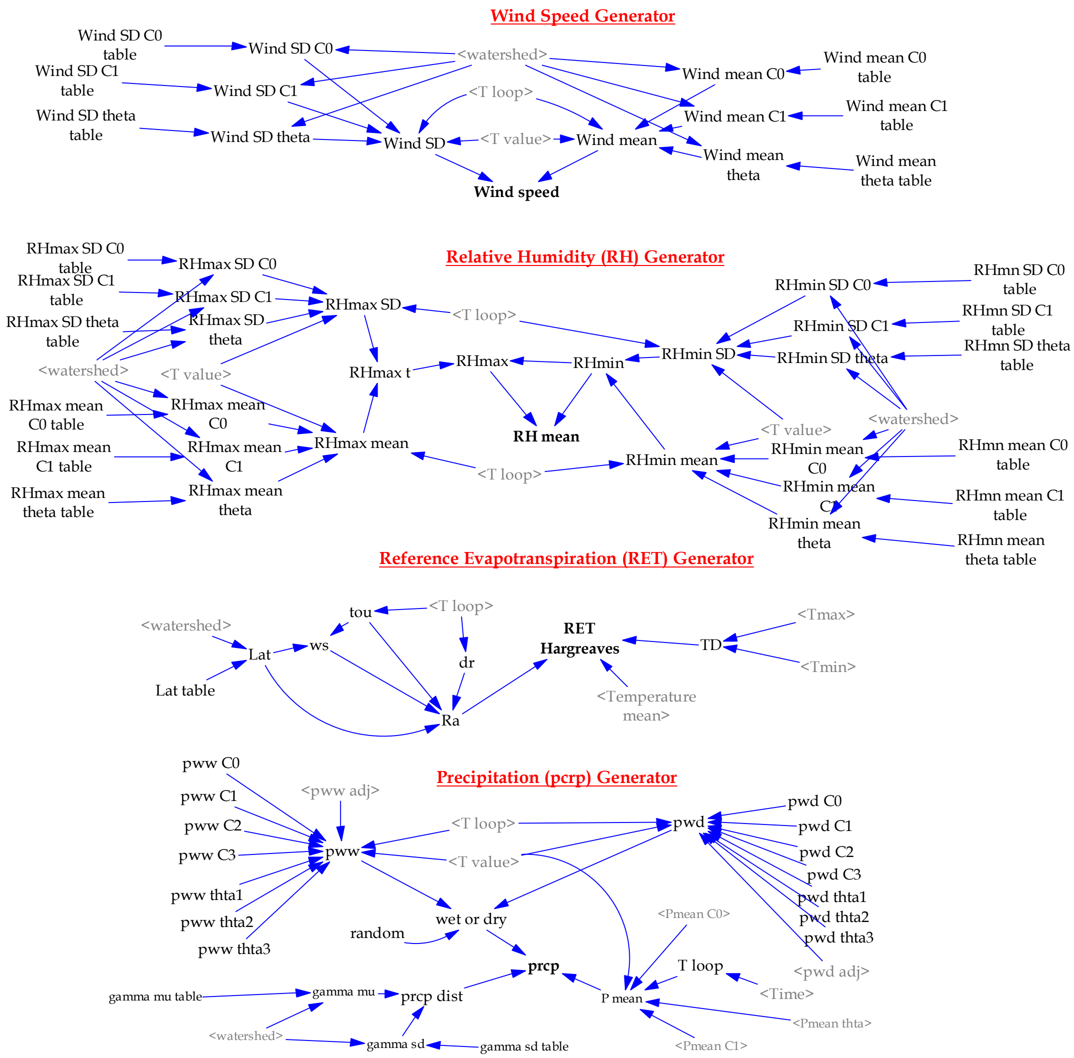
Water balance module



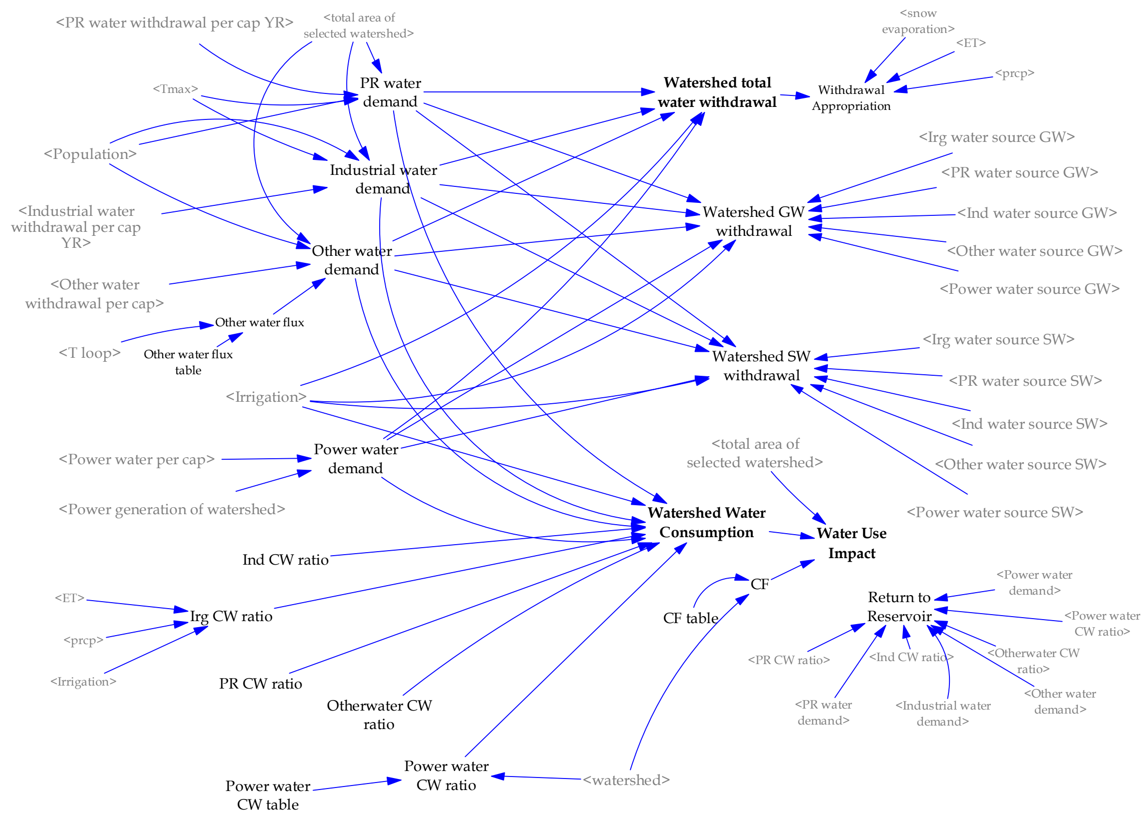
Climate module: temperature generator



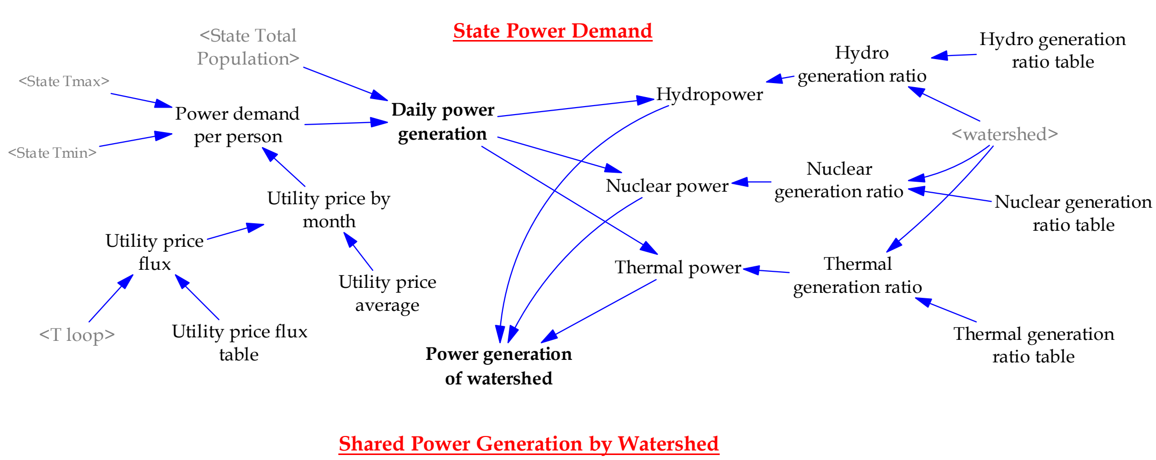
Climate module: wind speed, relative humidity, reference evapotranspiration, and precipitation generators



Water demand module

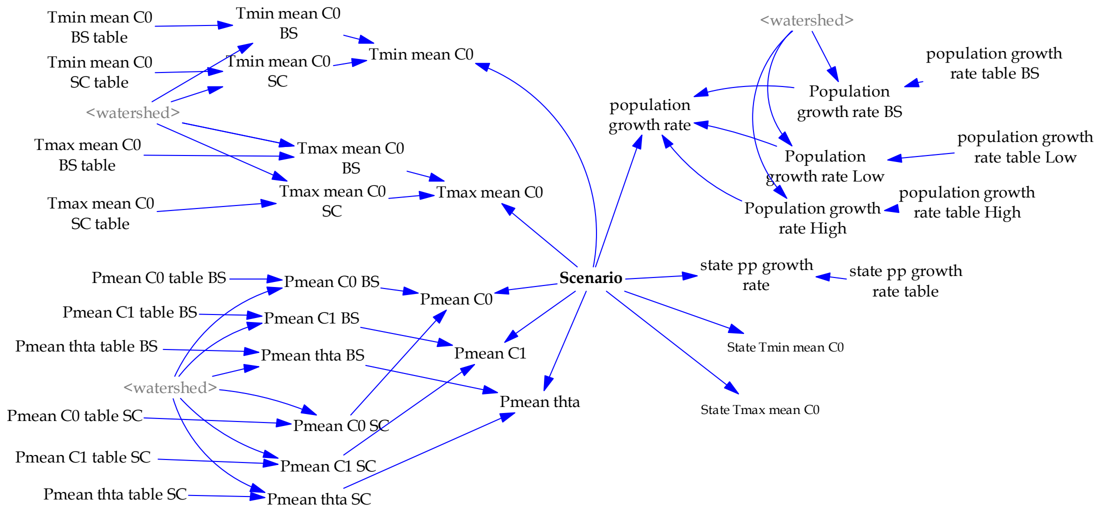


Energy module

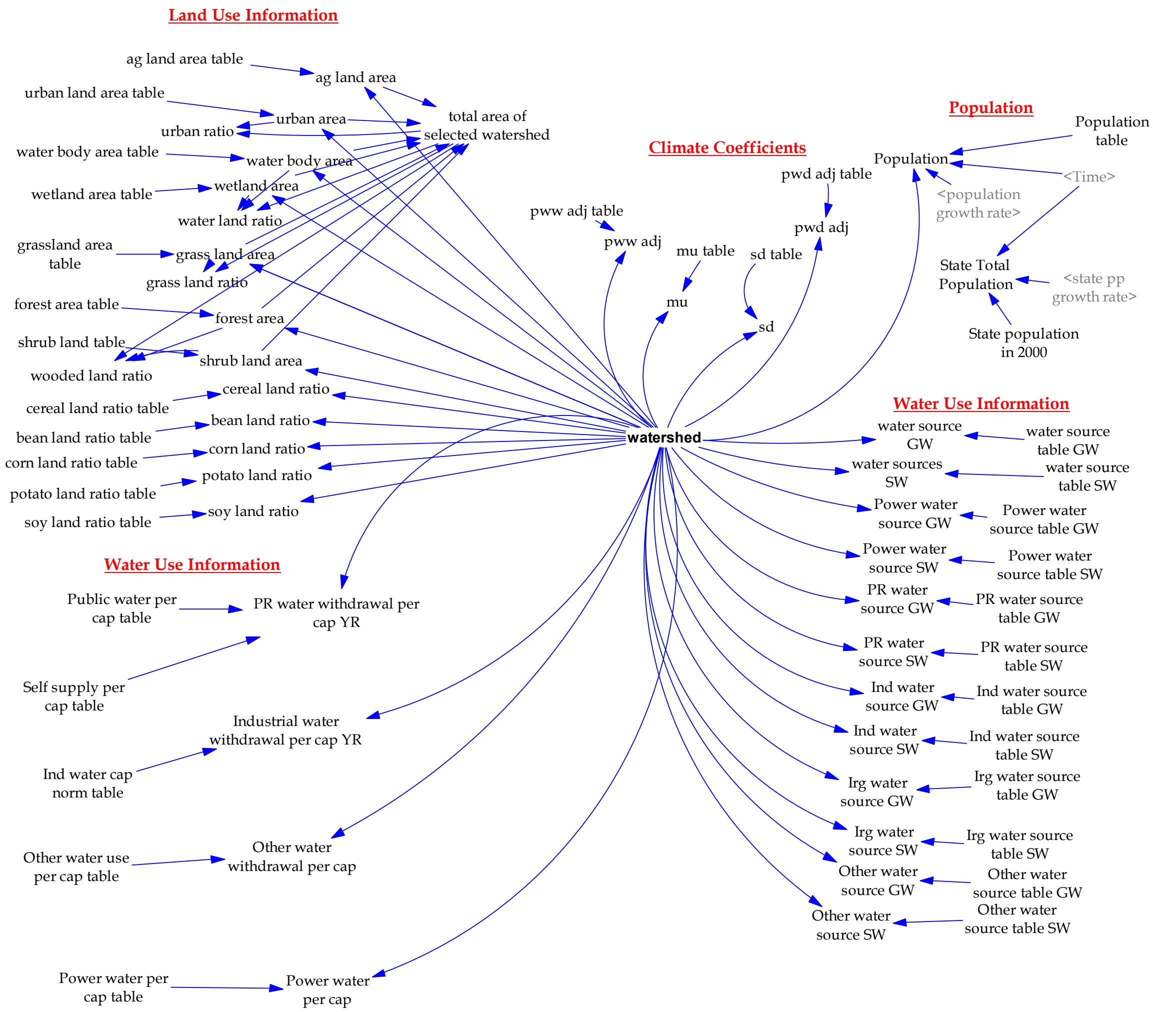


Supportive modules

Scenario selection module: when a particular scenario is chosen, related coefficients are selected accordingly.



Watershed selection: many coefficients are spatial-specific, therefore, are designed to be selected accordingly based on the selection of target watershed.



Appendix II – Result summary

Table A1. Background information by watershed: (a) water withdrawal per person per year by category, (b) population in 2000s and projection to 2030, and (c) power generation capacity by fuel type.

Watershed	Div.	Water withdrawal (m3/person/yr)				Population (1000 people)			Power generation (MWhr/yr)			
		Industrial	Public	Others	Self Supply	2000BL	2030BAU	Extreme	Hydro	Nuclear	Thermal	Wind
1	3	19723	49	16	46	7756	9830	11796	0	0	1411642	0
2	3	1513	483	13	18	95394	103878	124654	0	0	778297	0
3	3	173	45	250	16	217558	236287	283544	20433	0	1263758	0
4	3	0	0	0	16	196236	212083	254500	0	0	0	0
5	6	0	0	0	47	37798	57548	69058	0	0	0	0
7	2	6	39	5	51	41399	55692	66831	9608	0	7398188	0
8	2	1	12	0	67	31330	44016	52820	22450	0	0	0
9	6	286	69	94	43	45884	55690	66828	1840	0	0	0
10	6	100	153	7	49	41045	59515	71418	18719	0	1383	0
11	6	0	5	19	55	49348	74400	89280	0	0	0	0
12	2	47	50	0	57	30876	42414	50897	0	0	59163	0
13	4	0	11	0	43	51323	61671	74005	0	0	0	0
14	5	12	82	11	48	35928	47122	56546	0	0	40	0
15	5	171	55	2	28	78353	116067	139280	169388	0	88016	0
16	5	12	49	16	22	116723	174693	209632	0	0	-330	0
17	5	16	181	74	39	85616	189261	227113	0	4474918	13784682	0
18	5	8	55	20	20	120053	200801	240961	0	0	1193	0
19	5	30	71	6	12	90729	120554	144664	0	0	23700	0
20	6	16	415	39	4	791009	941586	1129903	60536	0	4687438	0
21	6	9	72	9	35	69193	117886	141463	0	0	1137	0
22	4	0	78	6	25	8975	8302	9963	0	0	0	0
23	4	19	72	6	37	25976	30157	36188	0	0	0	0
24	4	135	161	1	29	10647	9637	11564	0	0	0	0
25	7	26	327	18	24	20968	22246	26695	6477	0	41742	453083
26	4	19	134	23	36	21395	25570	30684	0	0	479	0
27	7	3	19	1	21	22104	22192	26630	0	0	0	0
28	8	60	407	136	20	34110	41777	50132	0	0	122950	0
29	7	44	203	20	22	23328	23910	28692	1512	0	2873	0
30	8	196	130	6	21	28027	29939	35927	0	0	407705	44092
31	8	5	134	5	18	22727	24533	29440	0	0	1220	0
32	8	17	100	2	21	40049	48859	58630	23499	0	42647	0
33	8	57	517	127	9	148127	234157	280988	0	0	2383771	0
34	6	1	2	0	59	32627	48014	57616	0	0	380	0
35	6	0	28	14	53	32958	49100	58920	258847	0	154	0
36	6	1	50	1	61	22564	34802	41762	0	0	642	0
37	6	12	104	8	21	128768	220822	264987	0	0	2797339	0
38	9	34	86	3	3	253356	372541	447050	37333	8360301	245403	0
39	9	15	161	30	9	90290	132278	158734	0	0	128322	0
40	9	38	83	54	17	71635	93769	112523	0	0	233	0
41	9	32	308	35	19	65300	98912	118694	12178	0	430487	95059
42	9	0	11	48	20	48736	54128	64953	0	0	0	0
43	9	6	67	306	23	44548	57686	69223	68	0	280502	0
44	9	1	17	0	33	24249	29085	34902	0	0	0	0
46	9	0	19	12	26	33518	39111	46934	0	0	0	0
47	9	0	0	0	19	47476	53994	64793	0	0	0	0
48	9	86	117	1	20	42476	48474	58169	0	0	144652	56952
49	8	9	119	0	21	40072	42178	50614	0	0	0	0

50	8	0	2	0	21	39876	41961	50354	0	0	0	0
51	7	43	217	35	26	15411	15960	19152	0	0	28	338336
52	7	0	0	1	27	16052	16949	20339	0	0	0	0
53	8	0	13	0	19	23917	23451	28141	0	0	0	0
54	4	0	6	0	35	11356	11953	14343	0	0	0	0
55	4	0	55	0	30	9407	9707	11649	0	0	0	0
56	4	20	130	6	44	55731	68736	82483	3570	0	931012	0
57	4	0	178	0	11	31484	41591	49910	0	0	65	0
58	1	4	43	1	17	50061	68992	82790	0	0	35136	8021
59	1	0	24	0	18	14611	17225	20670	0	0	1	0
60	1	24	26	0	30	18955	24613	29536	0	0	0	0
61	1	1	15	0	22	33498	39006	46807	0	0	0	0
62	2	0	3	0	49	43354	64245	77094	0	0	0	0
63	1	16	392	4	30	27013	33958	40749	3277	0	35943	0
65	1	1	2	0	44	26163	36220	43465	0	0	0	0
66	1	7	34	3	31	20783	24970	29964	0	0	0	0
67	1	0	2	0	22	34677	40430	48516	0	0	0	0
68	1	0	49	11	29	13997	15062	18075	0	0	0	0
69	1	35	21	4	23	9337	8860	10633	0	0	0	0
70	1	0	56	0	35	12626	14072	16886	0	0	0	0
71	1	0	29	0	45	20048	25474	30569	0	0	0	0
72	3	0	10	101	18	90713	98854	118625	18770	0	77	0
73	3	0	1	0	16	246610	266137	319364	47344	0	45959	0
74	2	0	0	0	17	163528	175849	211018	0	0	135661	0
75	2	3573	51	0	33	17653	17321	20785	0	0	0	0
76	2	1	2	0	18	132978	143525	172230	0	0	0	0
77	2	0	3	1	42	35483	40079	48095	58880	0	0	0
78	2	0	0	0	47	16323	21106	25328	0	0	0	0
79	2	0	23	0	54	5561	5967	7161	0	0	0	0
80	2	0	40	0	50	8510	9880	11856	0	0	0	0
81	7	0	0	0	10	7902	7838	9405	0	0	0	0
82	7	0	290	2	9	11744	12228	14673	0	0	0	580494
83	7	4	130	0	17	17635	18619	22343	0	0	160	6084
84	7	0	0	0	25	17939	19295	23154	0	0	0	0

Table A2. Land use by watershed in million m^2, estimated based on 2000 satellite image.

Watershed	Water	Urban	Wetland	Agriculture	Forest	Grassland	Shrub Land	Total Area
1	226	95	583	1	3209	0	8	4125
2	15	108	74	34	1401	2	2	1638
3	196	498	1031	443	4994	7	218	7389
4	114	51	240	27	1611	0	13	2055
5	6	20	81	57	543	2	10	719
7	703	157	580	470	3114	14	41	5079
8	646	80	488	202	2031	3	8	3459
9	282	214	867	283	3591	11	126	5373
10	223	249	915	795	2079	36	74	4370
11	220	52	279	123	1346	2	10	2032
12	317	219	525	1403	2487	32	57	5039
13	33	108	235	1441	455	4	51	2328
14	166	162	270	1175	485	30	24	2313
15	59	192	575	1192	503	87	33	2641
16	112	223	282	1656	273	133	20	2700
17	95	346	399	1286	562	194	22	2905
18	235	344	553	2102	388	188	30	3841
19	109	292	292	2321	216	64	19	3312
20	219	1147	315	337	429	149	34	2630
21	585	270	577	1186	1215	151	52	4035
22	121	123	199	1226	50	223	30	1971
23	188	121	63	1610	153	126	5	2266
24	15	133	125	1388	52	235	23	1972
25	57	361	221	4170	236	283	43	5373
26	276	301	228	3742	333	467	24	5371
27	26	120	60	1397	61	127	35	1826
28	60	296	180	2576	247	111	21	3490
29	19	206	81	2773	134	151	36	3400
30	40	256	58	2640	97	34	13	3138
31	25	188	68	1885	53	41	13	2273
32	56	179	86	2417	89	46	9	2881
33	112	715	414	2825	434	178	36	4714
34	5	33	204	96	1055	4	19	1417
35	43	95	615	273	1647	10	37	2720
36	27	142	480	566	1353	17	27	2613
37	128	306	361	766	658	139	29	2389
38	78	210	71	743	322	120	22	1566
39	94	326	297	2432	395	220	44	3809
40	55	150	27	672	699	106	3	1713
41	9	335	62	2462	563	218	35	3684
42	7	22	10	39	133	11	0	222
43	2	313	8	2354	1282	314	23	4296
44	9	29	23	130	251	31	1	475
46	0	44	0	416	69	32	2	563
47	0	2	0	29	0	1	0	32
48	8	137	24	1558	51	46	15	1840
49	20	58	37	462	30	22	8	637
50	6	9	8	154	4	3	1	185
51	72	196	80	2560	98	168	55	3229
52	0	25	1	192	4	2	1	225
53	15	45	7	447	3	3	2	522
54	40	78	12	1260	13	52	5	1461
55	69	112	38	1941	32	75	12	2278
56	715	273	312	2664	1069	93	11	5136
57	1	84	7	1005	20	20	2	1140
58	84	123	75	2258	199	127	4	2871
59	2	47	9	910	29	15	3	1014
60	122	136	202	2735	935	77	13	4220
61	21	67	25	1243	84	16	4	1461
62	1214	75	770	390	2628	7	30	5114
63	13	127	507	2372	308	73	17	3417
65	30	60	544	1294	735	68	57	2789
66	83	133	356	2166	704	117	30	3588
67	5	56	21	1444	11	14	1	1553

Watershed	Water	Urban	Wetland	Agriculture	Forest	Grassland	Shrub Land	Total Area
68	0	75	64	1742	98	39	14	2033
69	4	94	99	1950	151	17	12	2327
70	2	86	234	2176	207	57	25	2788
71	7	107	439	1413	737	26	30	2758
72	801	65	1324	7	4283	0	15	6496
73	332	65	190	49	1941	0	104	2681
74	376	18	99	42	1788	0	31	2354
75	7	49	154	58	1070	0	18	1356
76	94	113	374	200	3855	0	137	4774
77	210	77	732	110	4205	1	34	5370
78	1	22	601	96	1504	0	95	2319
79	5	30	158	155	414	0	27	790
80	1230	60	440	397	827	4	21	2979
81	0	6	2	63	1	32	2	107
82	1	78	5	1034	13	162	29	1322
83	1	141	12	1905	27	245	44	2375
84	26	51	26	661	20	22	6	810

Table A3. Water availability, consumption, and withdrawal under different scenarios in various divisions. Figures are in mm/month and may not add up due to rounding and error. All regional simulated stream flows within 10% of historical records and system water residual within 10% of local precipitation would be accepted.

Figures listed in the tables are for analysis purposes and representing "most-possible" ranges. They should not be treated as absolute or exact quantities occurring in a hydro system.

Division	Indicator	scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	consumption	BL	0.01	0.01	0.03	0.06	0.09	0.19	0.32	0.24	0.08	0.06	0.03	0.01
1	consumption	CnBAU	0.01	0.01	0.04	0.07	0.11	0.21	0.35	0.27	0.10	0.07	0.03	0.01
1	consumption	Cx	0.01	0.01	0.04	0.06	0.09	0.23	0.33	0.27	0.09	0.06	0.03	0.01
1	consumption	CxBAU	0.01	0.02	0.05	0.08	0.12	0.25	0.36	0.30	0.11	0.08	0.04	0.02
1	consumption	EtOHn	0.01	0.01	0.03	0.06	0.09	0.19	0.32	0.24	0.08	0.06	0.03	0.01
1	consumption	Extreme	0.01	0.02	0.06	0.10	0.14	0.28	0.39	0.33	0.14	0.09	0.05	0.02
1	consumption	PPn	0.01	0.01	0.04	0.07	0.11	0.21	0.35	0.26	0.10	0.07	0.03	0.01
1	consumption	PWn	0.01	0.01	0.03	0.06	0.09	0.19	0.32	0.24	0.08	0.06	0.03	0.01
1	availability	BL	0.09	0.30	22.36	21.23	8.69	8.29	7.77	2.94	3.01	6.35	3.35	0.05
1	availability	CnBAU	0.08	0.33	21.58	21.24	9.39	7.91	8.02	3.10	3.25	6.32	2.95	0.05
1	availability	Cx	0.30	1.33	42.82	35.98	2.54	40.18	12.94	0.42	4.07	0.88	2.25	0.07
1	availability	CxBAU	0.32	1.38	43.73	34.97	2.69	36.69	11.68	0.48	4.12	0.83	2.13	0.07
1	availability	EtOHn	0.08	0.32	21.21	20.63	8.27	7.88	7.86	2.98	3.00	6.25	3.00	0.06
1	availability	Extreme	0.31	1.27	43.57	34.14	2.77	34.81	11.41	0.46	4.02	0.84	2.22	0.08
1	availability	PPn	0.07	0.32	21.11	20.91	8.73	8.14	8.42	2.91	2.59	4.96	2.39	0.04
1	availability	PWn	0.08	0.35	21.33	20.41	8.58	6.66	7.75	3.28	3.14	6.17	2.99	0.05
1	withdrawal	BL	0.01	0.01	0.04	0.07	0.11	0.23	0.40	0.30	0.10	0.07	0.03	0.01
1	withdrawal	CnBAU	0.01	0.02	0.05	0.09	0.13	0.26	0.43	0.33	0.12	0.08	0.04	0.01
1	withdrawal	Cx	0.01	0.02	0.04	0.07	0.11	0.28	0.41	0.33	0.11	0.07	0.04	0.02
1	withdrawal	CxBAU	0.01	0.02	0.05	0.09	0.14	0.31	0.45	0.36	0.13	0.09	0.05	0.02
1	withdrawal	EtOHn	0.01	0.01	0.04	0.07	0.11	0.23	0.40	0.30	0.10	0.07	0.03	0.01
1	withdrawal	Extreme	0.02	0.02	0.06	0.11	0.17	0.34	0.48	0.40	0.16	0.11	0.06	0.02
1	withdrawal	PPn	0.01	0.02	0.05	0.09	0.13	0.26	0.44	0.33	0.12	0.08	0.04	0.01
1	withdrawal	PWn	0.01	0.01	0.04	0.07	0.11	0.23	0.40	0.29	0.10	0.07	0.03	0.01
2	consumption	BL	0.18	0.18	0.23	0.28	0.37	0.53	0.76	0.65	0.38	0.30	0.22	0.18
2	consumption	CnBAU	0.36	0.34	0.40	0.45	0.57	0.76	1.01	0.91	0.60	0.50	0.39	0.36
2	consumption	Cx	0.18	0.18	0.24	0.29	0.38	0.60	0.78	0.70	0.40	0.31	0.23	0.19
2	consumption	CxBAU	0.36	0.34	0.41	0.46	0.58	0.83	1.05	0.97	0.63	0.51	0.40	0.37
2	consumption	EtOHn	0.18	0.18	0.23	0.28	0.37	0.53	0.75	0.65	0.37	0.30	0.22	0.18
2	consumption	Extreme	0.50	0.48	0.56	0.62	0.78	1.06	1.30	1.22	0.85	0.70	0.56	0.52
2	consumption	PPn	0.23	0.22	0.28	0.33	0.43	0.60	0.84	0.73	0.45	0.36	0.27	0.23
2	consumption	PWn	0.28	0.27	0.33	0.37	0.47	0.65	0.89	0.79	0.50	0.41	0.32	0.29
2	availability	BL	0.73	0.60	46.47	38.11	20.09	9.35	5.27	1.43	3.51	22.74	11.96	0.24
2	availability	CnBAU	0.68	0.60	46.21	38.51	20.56	9.14	5.27	1.45	3.41	22.83	12.10	0.28
2	availability	Cx	1.54	1.24	73.47	54.23	10.77	66.98	8.47	0.37	3.29	1.76	8.40	0.60

Division	Indicator	scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2	availability	CxBAU	1.55	1.21	73.49	54.22	11.05	65.26	7.97	0.37	3.25	1.78	8.37	0.60
2	availability	EtOHn	0.71	0.56	46.41	38.39	19.74	8.98	5.45	1.41	3.32	23.19	12.25	0.25
2	availability	Extreme	1.57	1.18	73.70	53.72	10.65	64.54	8.11	0.37	3.27	1.76	8.33	0.64
2	availability	PPn	0.70	0.62	45.84	38.70	19.99	9.35	5.54	1.39	3.02	22.66	12.43	0.27
2	availability	PWn	0.71	0.62	45.88	38.60	20.23	9.25	5.30	1.46	3.77	24.00	12.40	0.27
2	withdrawal	BL	0.45	0.42	0.51	0.57	0.72	0.96	1.30	1.16	0.76	0.63	0.49	0.45
2	withdrawal	CnBAU	0.90	0.84	0.95	1.00	1.21	1.51	1.93	1.79	1.32	1.13	0.94	0.91
2	withdrawal	Cx	0.45	0.43	0.52	0.59	0.74	1.06	1.33	1.23	0.80	0.65	0.51	0.46
2	withdrawal	CxBAU	0.90	0.84	0.96	1.02	1.24	1.62	1.99	1.89	1.37	1.16	0.95	0.91
2	withdrawal	EtOHn	0.45	0.42	0.51	0.57	0.72	0.97	1.30	1.16	0.76	0.63	0.49	0.45
2	withdrawal	Extreme	1.27	1.19	1.33	1.40	1.70	2.14	2.57	2.47	1.88	1.60	1.33	1.29
2	withdrawal	PPn	0.57	0.54	0.63	0.69	0.86	1.12	1.48	1.34	0.92	0.77	0.62	0.58
2	withdrawal	PWn	0.71	0.66	0.76	0.81	0.99	1.27	1.64	1.51	1.07	0.91	0.75	0.72
3	consumption	BL	0.42	0.47	0.83	1.26	1.77	2.10	2.32	2.16	1.68	1.22	0.72	0.45
3	consumption	CnBAU	0.70	0.74	1.17	1.65	2.28	2.67	2.98	2.79	2.21	1.64	1.05	0.75
3	consumption	Cx	0.43	0.49	0.87	1.29	1.82	2.15	2.38	2.21	1.73	1.25	0.75	0.48
3	consumption	CxBAU	0.71	0.76	1.20	1.70	2.33	2.74	3.05	2.86	2.26	1.69	1.09	0.77
3	consumption	EtOHn	0.41	0.46	0.83	1.25	1.76	2.08	2.31	2.14	1.67	1.21	0.72	0.45
3	consumption	Extreme	0.97	1.01	1.55	2.13	2.91	3.41	3.79	3.56	2.84	2.14	1.41	1.03
3	consumption	PPn	0.51	0.56	0.98	1.47	2.07	2.44	2.71	2.51	1.97	1.43	0.86	0.55
3	consumption	PWn	0.57	0.61	0.98	1.40	1.93	2.28	2.53	2.37	1.87	1.38	0.87	0.61
3	availability	BL	0.33	0.15	50.59	77.65	21.22	11.45	10.22	5.51	27.82	59.86	14.84	0.74
3	availability	CnBAU	0.33	0.15	50.77	77.71	22.27	10.68	9.82	5.04	26.88	58.56	13.51	0.74
3	availability	Cx	0.76	0.37	70.25	113.69	15.02	68.36	7.95	3.07	15.07	12.05	16.55	1.23
3	availability	CxBAU	0.76	0.38	69.87	115.87	15.74	65.41	6.66	3.05	14.25	11.79	16.59	1.23
3	availability	EtOHn	0.33	0.15	50.56	76.81	21.46	10.43	9.63	5.11	27.34	60.07	14.22	0.68
3	availability	Extreme	0.76	0.38	70.20	114.43	14.75	62.76	6.81	2.91	15.32	12.23	16.70	1.23
3	availability	PPn	0.33	0.14	50.67	76.53	21.15	11.08	10.41	4.59	25.84	57.54	14.30	0.68
3	availability	PWn	0.33	0.15	50.12	77.05	20.79	9.86	9.96	5.08	28.28	59.71	14.46	0.68
3	withdrawal	BL	0.76	0.81	1.34	1.94	2.72	3.19	3.56	3.33	2.62	1.93	1.19	0.81
3	withdrawal	CnBAU	1.47	1.48	2.11	2.78	3.75	4.37	4.89	4.64	3.72	2.86	1.95	1.53
3	withdrawal	Cx	0.78	0.83	1.39	1.99	2.78	3.27	3.63	3.40	2.68	1.98	1.24	0.84
3	withdrawal	CxBAU	1.48	1.50	2.15	2.83	3.83	4.47	5.00	4.74	3.81	2.93	2.00	1.55
3	withdrawal	EtOHn	0.76	0.81	1.34	1.94	2.72	3.19	3.56	3.33	2.62	1.93	1.19	0.81
3	withdrawal	Extreme	2.06	2.06	2.86	3.67	4.91	5.71	6.40	6.09	4.93	3.84	2.68	2.15
3	withdrawal	PPn	0.96	1.00	1.63	2.31	3.22	3.78	4.21	3.94	3.12	2.32	1.46	1.02
3	withdrawal	PWn	1.16	1.18	1.72	2.30	3.13	3.65	4.09	3.86	3.09	2.36	1.58	1.21
4	consumption	BL	0.12	0.11	0.14	0.17	0.21	0.56	0.83	0.65	0.24	0.19	0.14	0.12
4	consumption	CnBAU	0.21	0.20	0.24	0.27	0.33	0.71	0.98	0.81	0.38	0.31	0.24	0.22
4	consumption	Cx	0.12	0.11	0.14	0.17	0.23	0.64	0.84	0.69	0.28	0.19	0.15	0.13
4	consumption	CxBAU	0.22	0.21	0.24	0.27	0.35	0.78	1.01	0.85	0.41	0.32	0.25	0.23
4	consumption	EtOHn	0.12	0.11	0.14	0.17	0.22	0.57	0.82	0.67	0.25	0.19	0.14	0.12

Division	Indicator	scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4	consumption	Extreme	0.30	0.28	0.33	0.37	0.46	0.92	1.15	0.99	0.54	0.42	0.34	0.31
4	consumption	PPn	0.14	0.14	0.17	0.20	0.26	0.62	0.88	0.72	0.30	0.23	0.18	0.15
4	consumption	PWn	0.17	0.16	0.19	0.21	0.27	0.63	0.89	0.72	0.31	0.24	0.19	0.18
4	availability	BL	0.57	0.53	23.77	24.99	10.00	7.07	7.60	3.92	3.40	4.76	4.35	0.32
4	availability	CnBAU	0.55	0.63	22.38	24.16	10.70	6.40	7.89	4.14	3.72	4.79	4.19	0.32
4	availability	Cx	1.21	1.72	60.12	55.67	1.80	21.36	3.69	1.00	3.49	0.87	2.60	0.30
4	availability	CxBAU	1.22	1.83	60.24	54.07	1.62	20.16	3.41	0.98	3.25	0.71	2.46	0.28
4	availability	EtOHn	0.51	0.53	22.39	24.33	9.63	6.89	7.28	3.64	3.59	4.54	3.93	0.28
4	availability	Extreme	1.27	1.91	60.74	50.98	1.64	18.50	3.44	1.01	3.39	0.61	2.90	0.27
4	availability	PPn	0.53	0.55	21.74	23.35	9.59	6.62	7.93	3.52	2.81	3.69	3.11	0.22
4	availability	PWn	0.53	0.55	22.03	23.16	10.95	5.78	8.05	4.32	3.66	5.15	4.36	0.38
4	withdrawal	BL	0.25	0.24	0.28	0.32	0.40	1.31	1.99	1.54	0.48	0.36	0.29	0.26
4	withdrawal	CnBAU	0.49	0.46	0.52	0.55	0.68	1.64	2.33	1.90	0.80	0.64	0.53	0.51
4	withdrawal	Cx	0.25	0.24	0.29	0.32	0.43	1.51	2.01	1.62	0.57	0.37	0.29	0.27
4	withdrawal	CxBAU	0.49	0.46	0.53	0.57	0.72	1.84	2.41	2.00	0.89	0.66	0.54	0.51
4	withdrawal	EtOHn	0.25	0.24	0.28	0.32	0.40	1.33	1.97	1.56	0.49	0.37	0.29	0.26
4	withdrawal	Extreme	0.69	0.65	0.73	0.77	0.97	2.13	2.72	2.31	1.16	0.90	0.75	0.71
4	withdrawal	PPn	0.32	0.30	0.35	0.39	0.50	1.43	2.10	1.69	0.59	0.45	0.36	0.33
4	withdrawal	PWn	0.39	0.36	0.41	0.44	0.54	1.49	2.16	1.70	0.65	0.51	0.42	0.40
5	consumption	BL	1.04	0.97	1.10	1.18	1.44	2.58	3.59	2.88	1.68	1.36	1.13	1.07
5	consumption	CnBAU	2.11	1.97	2.20	2.31	2.80	4.15	5.38	4.66	3.20	2.69	2.25	2.17
5	consumption	Cx	1.04	0.97	1.11	1.20	1.52	2.82	3.69	2.99	1.84	1.40	1.15	1.08
5	consumption	CxBAU	2.11	1.97	2.22	2.36	2.93	4.42	5.56	4.82	3.41	2.76	2.28	2.18
5	consumption	EtOHn	1.04	0.97	1.10	1.18	1.44	2.60	3.58	2.89	1.68	1.36	1.13	1.07
5	consumption	Extreme	2.95	2.75	3.06	3.22	3.95	5.60	6.90	6.17	4.57	3.77	3.15	3.04
5	consumption	PPn	1.36	1.28	1.48	1.63	2.03	3.27	4.36	3.65	2.32	1.89	1.53	1.42
5	consumption	PWn	1.62	1.51	1.65	1.71	2.05	3.28	4.38	3.66	2.37	1.99	1.69	1.65
5	availability	BL	0.58	1.08	30.08	23.48	14.62	11.57	9.86	5.77	6.54	12.60	14.05	1.47
5	availability	CnBAU	0.55	1.01	29.37	23.40	15.47	11.34	9.96	5.94	6.58	11.98	13.26	1.35
5	availability	Cx	1.36	3.05	68.93	50.44	2.40	24.91	6.15	4.37	3.83	0.95	7.44	1.34
5	availability	CxBAU	1.25	3.10	70.63	50.22	2.45	22.42	5.74	4.41	3.86	0.93	7.07	1.41
5	availability	EtOHn	0.55	1.02	29.13	22.47	14.08	11.19	10.12	5.80	6.45	12.68	13.62	1.37
5	availability	Extreme	1.31	3.08	70.54	49.06	2.66	21.27	5.74	4.30	3.67	0.65	6.68	1.41
5	availability	PPn	0.62	1.03	29.32	23.04	15.40	11.34	10.47	5.73	5.76	10.67	12.21	1.26
5	availability	PWn	0.58	1.07	28.49	22.19	14.68	9.75	9.94	6.30	6.53	11.67	13.87	1.43
5	withdrawal	BL	2.38	2.21	2.40	2.45	2.92	4.51	6.01	5.10	3.39	2.86	2.45	2.42
5	withdrawal	CnBAU	4.88	4.51	4.87	4.91	5.81	7.77	9.76	8.86	6.64	5.75	4.96	4.94
5	withdrawal	Cx	2.37	2.20	2.41	2.49	3.04	4.85	6.17	5.28	3.62	2.93	2.48	2.42
5	withdrawal	CxBAU	4.84	4.48	4.88	4.99	6.02	8.20	10.08	9.15	6.97	5.88	5.02	4.94
5	withdrawal	EtOHn	2.38	2.21	2.40	2.45	2.92	4.52	5.99	5.11	3.39	2.86	2.45	2.42
5	withdrawal	Extreme	6.82	6.31	6.83	6.93	8.29	10.79	13.05	12.14	9.57	8.18	7.02	6.95
5	withdrawal	PPn	3.07	2.85	3.15	3.27	3.93	5.68	7.33	6.43	4.51	3.82	3.22	3.14

Division	Indicator	scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5	withdrawal	PWn	3.79	3.50	3.74	3.73	4.38	6.16	7.89	6.98	5.06	4.37	3.81	3.83
6	consumption	BL	1.42	1.29	1.42	1.39	1.50	1.55	1.67	1.67	1.53	1.50	1.39	1.42
6	consumption	CnBAU	2.40	2.19	2.40	2.35	2.55	2.64	2.87	2.86	2.63	2.54	2.36	2.41
6	consumption	Cx	1.46	1.33	1.46	1.44	1.56	1.61	1.74	1.73	1.59	1.55	1.44	1.46
6	consumption	CxBAU	2.43	2.21	2.43	2.40	2.61	2.71	2.95	2.94	2.70	2.60	2.40	2.44
6	consumption	EtOHn	1.42	1.29	1.42	1.40	1.51	1.55	1.68	1.67	1.54	1.50	1.40	1.43
6	consumption	Extreme	3.26	2.97	3.26	3.21	3.50	3.63	3.95	3.95	3.62	3.49	3.22	3.28
6	consumption	PPn	1.78	1.62	1.79	1.77	1.92	1.98	2.15	2.14	1.96	1.90	1.76	1.79
6	consumption	PWn	1.90	1.73	1.89	1.85	2.00	2.06	2.24	2.24	2.05	2.00	1.86	1.91
6	availability	BL	1.51	0.96	48.73	38.66	22.89	16.34	12.16	4.64	11.57	33.73	25.74	1.55
6	availability	CnBAU	1.52	0.87	48.52	39.01	24.19	15.42	11.64	4.49	11.69	32.12	24.22	1.48
6	availability	Cx	2.85	2.73	82.11	66.67	11.42	53.70	11.69	1.99	3.63	2.02	15.84	2.37
6	availability	CxBAU	2.77	2.67	83.15	67.19	12.02	51.90	10.47	1.96	3.57	1.95	14.78	2.41
6	availability	EtOHn	1.51	0.96	48.45	38.41	23.28	15.07	11.37	4.52	11.60	32.73	24.94	1.55
6	availability	Extreme	2.78	2.58	83.18	66.30	11.36	48.38	10.65	1.91	3.62	1.88	15.62	2.46
6	availability	PPn	1.51	0.86	48.06	38.96	23.05	16.05	12.57	4.23	10.74	31.00	24.53	1.58
6	availability	PWn	1.49	0.94	48.22	37.93	22.53	14.76	11.84	4.81	12.03	33.76	25.72	1.63
6	withdrawal	BL	2.50	2.37	2.84	3.23	4.10	4.89	5.71	5.53	4.49	3.74	2.94	2.63
6	withdrawal	CnBAU	4.94	4.62	5.26	5.67	6.97	8.14	9.46	9.27	7.74	6.60	5.41	5.10
6	withdrawal	Cx	2.53	2.39	2.87	3.30	4.21	5.06	5.87	5.70	4.64	3.84	3.00	2.66
6	withdrawal	CxBAU	4.94	4.62	5.31	5.79	7.17	8.42	9.74	9.56	7.98	6.76	5.49	5.12
6	withdrawal	EtOHn	2.50	2.37	2.84	3.23	4.09	4.89	5.71	5.53	4.49	3.74	2.94	2.63
6	withdrawal	Extreme	6.91	6.44	7.32	7.86	9.66	11.25	13.00	12.80	10.77	9.20	7.55	7.14
6	withdrawal	PPn	3.20	3.01	3.60	4.09	5.17	6.12	7.12	6.92	5.67	4.74	3.72	3.35
6	withdrawal	PWn	3.87	3.62	4.13	4.47	5.51	6.46	7.53	7.37	6.10	5.20	4.25	3.99
7	consumption	BL	0.06	0.05	0.07	0.09	0.11	0.15	0.17	0.15	0.11	0.10	0.07	0.06
7	consumption	CnBAU	0.07	0.06	0.08	0.10	0.12	0.16	0.18	0.17	0.13	0.11	0.09	0.07
7	consumption	Cx	0.06	0.06	0.07	0.09	0.11	0.15	0.17	0.16	0.12	0.10	0.08	0.06
7	consumption	CxBAU	0.07	0.07	0.09	0.10	0.13	0.17	0.19	0.17	0.13	0.11	0.09	0.08
7	consumption	EtOHn	0.06	0.06	0.08	0.09	0.11	0.15	0.17	0.16	0.12	0.10	0.08	0.07
7	consumption	Extreme	0.09	0.08	0.11	0.13	0.16	0.20	0.22	0.20	0.16	0.14	0.11	0.09
7	consumption	PPn	0.06	0.06	0.08	0.09	0.12	0.16	0.18	0.16	0.12	0.10	0.08	0.06
7	consumption	PWn	0.06	0.06	0.07	0.09	0.11	0.15	0.17	0.16	0.12	0.10	0.08	0.06
7	availability	BL	1.50	2.33	27.50	24.43	10.19	5.36	6.28	3.11	2.63	2.75	4.50	1.85
7	availability	CnBAU	1.41	2.31	27.37	23.98	10.42	5.08	6.25	3.07	2.61	2.54	4.07	1.80
7	availability	Cx	2.44	5.14	66.43	34.03	0.88	6.66	3.19	1.72	2.15	0.08	0.75	0.30
7	availability	CxBAU	2.45	5.40	67.04	34.85	0.79	6.47	3.06	1.73	2.14	0.08	0.69	0.29
7	availability	EtOHn	1.50	2.45	27.09	24.09	10.33	5.26	6.22	3.12	2.73	2.58	4.12	1.70
7	availability	Extreme	2.51	5.24	68.23	33.87	0.91	6.40	3.11	1.70	2.23	0.08	0.62	0.22
7	availability	PPn	1.46	2.48	26.71	24.94	10.20	5.30	6.38	3.05	2.63	2.27	3.58	1.70
7	availability	PWn	1.42	2.44	26.58	23.96	10.38	4.97	6.33	3.24	2.58	2.65	4.19	1.80
7	withdrawal	BL	0.21	0.20	0.25	0.28	0.36	0.48	0.56	0.52	0.40	0.33	0.26	0.23

Division	Indicator	scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7	withdrawal	CnBAU	0.41	0.38	0.44	0.47	0.57	0.72	0.83	0.79	0.64	0.55	0.45	0.43
7	withdrawal	Cx	0.22	0.20	0.25	0.29	0.38	0.50	0.57	0.53	0.42	0.34	0.26	0.23
7	withdrawal	CxBAU	0.41	0.38	0.44	0.48	0.59	0.74	0.85	0.81	0.66	0.56	0.46	0.43
7	withdrawal	EtOHn	0.22	0.21	0.25	0.29	0.37	0.49	0.57	0.53	0.41	0.34	0.26	0.23
7	withdrawal	Extreme	0.57	0.53	0.60	0.64	0.79	0.97	1.11	1.07	0.89	0.76	0.62	0.59
7	withdrawal	PPn	0.27	0.25	0.30	0.33	0.42	0.55	0.64	0.60	0.47	0.39	0.31	0.28
7	withdrawal	PWn	0.32	0.30	0.35	0.38	0.48	0.61	0.70	0.67	0.53	0.45	0.36	0.34
8	consumption	BL	0.67	0.64	0.81	0.96	1.23	1.46	1.66	1.59	1.32	1.09	0.84	0.72
8	consumption	CnBAU	1.26	1.19	1.45	1.67	2.10	2.45	2.78	2.69	2.27	1.91	1.50	1.33
8	consumption	Cx	0.69	0.65	0.83	0.99	1.27	1.50	1.70	1.64	1.36	1.12	0.86	0.74
8	consumption	CxBAU	1.27	1.20	1.47	1.70	2.15	2.51	2.85	2.76	2.33	1.95	1.53	1.35
8	consumption	EtOHn	0.69	0.65	0.82	0.98	1.25	1.48	1.68	1.61	1.34	1.11	0.85	0.74
8	consumption	Extreme	1.73	1.63	1.97	2.23	2.80	3.25	3.68	3.59	3.04	2.57	2.03	1.83
8	consumption	PPn	0.88	0.84	1.09	1.32	1.71	2.02	2.28	2.20	1.83	1.50	1.14	0.96
8	consumption	PWn	0.96	0.90	1.08	1.22	1.53	1.79	2.03	1.97	1.65	1.40	1.11	1.00
8	availability	BL	1.71	2.54	33.26	36.19	23.96	10.17	8.43	5.63	5.62	7.47	7.99	2.07
8	availability	CnBAU	1.68	2.66	31.65	35.31	25.76	10.67	9.20	5.80	6.82	8.82	9.94	2.28
8	availability	Cx	2.64	4.83	64.24	51.78	6.64	12.19	6.11	4.96	1.93	1.59	4.97	1.28
8	availability	CxBAU	2.75	5.23	64.42	49.21	7.56	10.34	5.42	4.75	1.69	0.67	3.35	1.06
8	availability	EtOHn	1.72	2.82	31.90	36.12	23.88	11.39	8.18	5.33	6.14	8.40	8.47	2.35
8	availability	Extreme	2.72	5.25	64.44	48.51	7.64	10.31	5.56	4.79	1.63	0.57	4.08	1.03
8	availability	PPn	1.63	2.61	30.60	35.76	22.41	10.56	9.71	4.94	5.11	6.85	7.69	2.19
8	availability	PWn	1.75	2.63	31.00	35.42	26.07	10.06	8.78	6.56	6.48	9.25	9.45	2.36
8	withdrawal	BL	1.37	1.28	1.52	1.71	2.15	2.54	2.92	2.84	2.37	1.99	1.58	1.44
8	withdrawal	CnBAU	2.72	2.54	2.91	3.15	3.88	4.50	5.17	5.08	4.30	3.68	3.01	2.82
8	withdrawal	Cx	1.38	1.29	1.54	1.75	2.21	2.62	3.00	2.92	2.44	2.04	1.61	1.45
8	withdrawal	CxBAU	2.72	2.54	2.94	3.21	3.99	4.63	5.32	5.22	4.42	3.76	3.05	2.83
8	withdrawal	EtOHn	1.39	1.30	1.54	1.73	2.17	2.56	2.94	2.86	2.39	2.01	1.60	1.45
8	withdrawal	Extreme	3.79	3.54	4.03	4.34	5.35	6.18	7.10	7.00	5.95	5.10	4.18	3.93
8	withdrawal	PPn	1.77	1.67	2.00	2.28	2.90	3.40	3.90	3.80	3.17	2.66	2.09	1.87
8	withdrawal	PWn	2.10	1.96	2.22	2.38	2.92	3.39	3.90	3.83	3.24	2.78	2.29	2.17
9	consumption	BL	1.79	1.66	1.84	1.92	2.32	2.91	3.42	3.30	2.64	2.23	1.89	1.83
9	consumption	CnBAU	3.58	3.31	3.60	3.67	4.36	5.21	6.06	5.94	4.94	4.28	3.67	3.64
9	consumption	Cx	1.78	1.66	1.85	1.95	2.39	3.01	3.52	3.40	2.73	2.28	1.91	1.83
9	consumption	CxBAU	3.55	3.29	3.61	3.72	4.48	5.37	6.24	6.12	5.09	4.36	3.70	3.63
9	consumption	EtOHn	1.79	1.67	1.85	1.93	2.32	2.92	3.43	3.31	2.64	2.24	1.89	1.84
9	consumption	Extreme	4.97	4.60	5.01	5.13	6.14	7.24	8.41	8.29	6.97	6.03	5.15	5.07
9	consumption	PPn	2.31	2.15	2.39	2.51	3.04	3.73	4.35	4.22	3.43	2.91	2.44	2.36
9	consumption	PWn	2.79	2.58	2.79	2.83	3.35	4.06	4.75	4.64	3.81	3.30	2.84	2.83
9	availability	BL	3.78	2.10	43.68	35.75	23.90	11.24	9.48	5.29	6.07	19.06	25.34	5.61
9	availability	CnBAU	3.62	2.26	43.83	34.76	25.08	11.14	9.58	5.39	6.38	18.53	24.73	5.65
9	availability	Cx	4.45	3.52	70.68	52.85	9.17	13.11	8.80	6.63	0.77	1.01	11.73	4.12

Division	Indicator	scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9	availability	CxBAU	4.53	3.74	70.42	53.63	9.58	12.67	8.45	6.53	0.77	0.85	11.11	3.85
9	availability	EtOHn	3.74	2.08	44.23	34.66	23.94	10.74	9.43	5.27	6.05	17.91	24.48	5.58
9	availability	Extreme	4.45	3.71	72.32	52.88	8.69	11.64	8.39	6.44	0.71	0.83	10.82	3.93
9	availability	PPn	3.59	2.04	43.89	34.42	24.41	10.81	9.91	5.12	5.75	17.21	23.83	5.40
9	availability	PWn	3.75	2.13	43.46	34.38	24.05	9.96	9.66	5.43	6.23	19.19	25.97	5.72
9	withdrawal	BL	3.55	3.28	3.54	3.57	4.23	5.12	6.01	5.87	4.82	4.18	3.61	3.60
9	withdrawal	CnBAU	7.22	6.66	7.10	7.05	8.24	9.62	11.20	11.09	9.38	8.26	7.22	7.29
9	withdrawal	Cx	3.52	3.25	3.54	3.62	4.35	5.29	6.18	6.04	4.98	4.26	3.64	3.59
9	withdrawal	CxBAU	7.14	6.59	7.09	7.13	8.46	9.93	11.55	11.43	9.67	8.42	7.27	7.25
9	withdrawal	EtOHn	3.56	3.28	3.55	3.57	4.23	5.13	6.01	5.87	4.82	4.18	3.61	3.60
9	withdrawal	Extreme	10.06	9.28	9.94	9.96	11.76	13.64	15.85	15.74	13.41	11.76	10.20	10.20
9	withdrawal	PPn	4.56	4.21	4.57	4.62	5.49	6.55	7.64	7.50	6.23	5.41	4.66	4.63
9	withdrawal	PWn	5.63	5.19	5.52	5.46	6.38	7.52	8.78	8.67	7.28	6.40	5.61	5.68

Table A4. Water withdrawal (in million m^3/year) by user group by division under different scenarios. For ethanol (EtOH) and oil refineries (Ptro), water withdrawal (WU) and consumption (Wc) are also summarized. Oil refineries are assumed to acquire only make-up water for balancing water loss through vapor or waste water treatment. Therefore, only water consumption is listed under the oil refinery category (Ptro Wc).

Figures listed in the tables are for analysis purposes and representing "most-possible" values. They should not be treated as absolute or exact quantities occurring in a hydro system.

Statistics	Division	2000BL	Cx	PPn	EtOHn	PWn	CxBAU	CnBAU	Extreme
Public	1	23.9	25.6	29.8	23.9	23.9	31.9	29.8	38.3
Public	2	21.4	22.6	26.8	21.4	21.4	28.4	26.8	34.1
Public	3	68.2	70.9	74.2	68.2	68.2	77.2	74.3	92.7
Public	4	30.0	31.4	35.4	30.0	29.7	37.7	35.7	45.2
Public	5	57.8	60.5	99.4	57.8	57.5	104.7	99.6	125.6
Public	6	413.9	429.9	511.5	413.7	413.5	531.5	510.9	637.8
Public	7	26.7	26.9	27.2	26.8	26.1	28.7	27.9	34.5
Public	8	123.7	128.2	178.4	127.0	123.9	187.7	181.5	225.4
Public	9	89.6	91.9	126.1	89.8	89.3	130.2	126.6	156.3
Power	1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Power	2	213.5	216.5	273.3	213.5	343.7	446.2	440.0	631.9
Power	3	204.5	207.4	261.8	204.5	329.3	427.5	421.5	605.3
Power	4	69.3	70.3	88.7	69.3	111.6	144.9	142.8	205.1
Power	5	527.0	534.4	674.6	527.0	848.4	1101.5	1086.1	1559.7
Power	6	814.9	826.4	1043.2	814.9	1312.0	1703.3	1679.6	2411.9
Power	7	42.9	43.5	54.9	42.9	69.0	89.6	88.4	126.9
Power	8	276.0	279.9	353.3	276.0	444.4	576.9	568.9	816.9
Power	9	798.0	809.3	1021.6	798.1	1284.8	1668.1	1644.8	2362.0
Industry	1	1.5	1.6	1.9	1.5	1.5	2.0	1.9	2.4
Industry	2	61.7	65.5	61.2	61.8	61.7	65.0	61.3	78.0
Industry	3	315.2	323.9	368.4	315.2	315.2	378.2	368.4	454.5
Industry	4	3.7	4.2	4.3	4.5	4.0	4.9	4.8	5.9
Industry	5	21.1	22.2	31.8	21.1	21.0	33.6	31.9	40.4
Industry	6	20.2	21.4	26.7	20.1	20.1	28.4	26.7	34.0
Industry	7	2.6	3.4	3.5	4.0	3.4	4.2	4.1	5.0
Industry	8	18.5	19.4	25.2	19.1	18.8	26.4	25.6	31.7
Industry	9	20.7	21.6	27.9	21.4	21.3	28.4	28.0	34.1
Irrigation	1	16.6	19.2	16.6	16.5	16.4	19.4	16.6	19.4
Irrigation	2	29.2	34.3	29.2	29.2	29.1	34.5	29.1	34.6
Irrigation	3	2.2	2.4	2.2	2.2	2.2	2.4	2.2	2.4

Statistics	Division	2000BL	Cx	PPn	EtOHn	PWn	CxBAU	CnBAU	Extreme
Irrigation	4	81.6	89.6	82.3	81.9	81.0	90.4	81.5	90.5
Irrigation	5	86.8	95.8	87.2	86.8	86.8	96.4	87.3	96.6
Irrigation	6	23.3	26.1	23.4	23.3	23.2	26.3	23.4	26.3
Irrigation	7	4.1	4.3	4.1	4.1	4.1	4.3	4.1	4.3
Irrigation	8	5.0	5.2	5.0	4.9	4.9	5.3	4.9	5.3
Irrigation	9	26.7	28.3	26.8	26.6	26.6	28.4	26.6	28.4
Ptro Wc	1	--	--	--	--	--	--	--	--
Ptro Wc	2	--	--	--	--	--	--	--	--
Ptro Wc	3	--	--	--	--	--	--	--	--
Ptro Wc	4	--	--	--	--	--	--	--	--
Ptro Wc	5	--	--	--	--	--	--	--	--
Ptro Wc	6	0.3	0.3	0.4	0.3	0.3	0.3	0.4	0.4
Ptro Wc	7	--	--	--	--	--	--	--	--
Ptro Wc	8	--	--	--	--	--	--	--	--
Ptro Wc	9	0.6	0.7	0.9	0.7	0.7	0.9	0.9	1.1
EtOH Wc	1	--	--	--	0.0	--	0.0	0.0	0.0
EtOH Wc	2	--	--	--	0.0	--	0.0	0.0	0.0
EtOH Wc	3	--	--	--	--	--	--	--	--
EtOH Wc	4	0.5	0.5	0.5	0.7	0.5	0.8	0.7	0.9
EtOH Wc	5	0.5	0.5	0.4	0.5	0.4	0.6	0.5	0.7
EtOH Wc	6	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1
EtOH Wc	7	0.3	0.2	0.2	0.4	0.2	0.4	0.4	0.5
EtOH Wc	8	0.7	0.8	0.8	1.4	0.8	1.4	1.4	1.7
EtOH Wc	9	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.4
EtOH WU	1	--	--	--	0.0	--	0.0	0.0	0.0
EtOH WU	2	--	--	--	0.0	--	0.0	0.0	0.0
EtOH WU	3	--	--	--	--	--	--	--	--
EtOH WU	4	0.6	0.6	0.6	0.9	0.6	1.0	0.9	1.0
EtOH WU	5	0.6	0.6	0.5	0.6	0.5	0.7	0.6	0.9
EtOH WU	6	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1
EtOH WU	7	0.3	0.2	0.2	0.4	0.2	0.4	0.4	0.5
EtOH WU	8	0.7	0.8	0.8	1.4	0.8	1.4	1.4	1.7
EtOH WU	9	0.3	0.2	0.2	0.3	0.2	0.3	0.3	0.5