The Watershed Intelligence Engine

By Jim Blackburn, Jed Anderson and Chris Ordoñez

Texas has a water problem. It has been present for a long time, and it has been addressed with patches and omissions rather than a comprehensive plan. That situation must and will change as is discussed throughout this paper.

There are those that might suggest that we should not entertain a serious discussion of a different view of water management because we have a legal system that has been adopted and in use for decades. However, it is worth noting that information is taking us beyond legal structures at great speed. Consider the global climate situation. In the United States, we have no comprehensive legal requirement to address carbon dioxide emissions, yet almost every corporation in the United States has developed and/or is developing a carbon dioxide abatement program. This is based upon factors beyond the legal system and is part of an information revolution.

There are basic concepts about the functioning of the Earth that are beyond the law. These can be called "Earth Rules". These are rules established over the eons about what is required for the Earth to function as a habitable place for humans and current plant and animal life. These earth rules include the principles that keep the Earth functioning including the carbon cycle relative to climate and the hydrologic cycle relative to water. This complex interrelated system is shown in Figure 1.

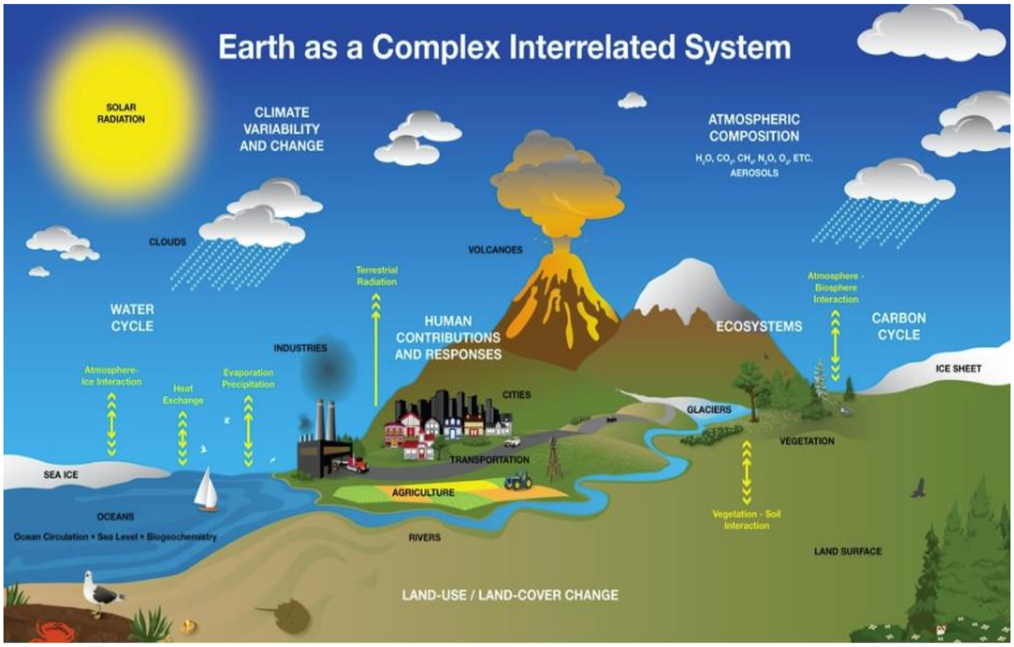

Figure 1. Image of the Earth as a complex system with both a carbon and water cycle inherent in its function. https://www.sciencelearn.org.nz/resources/3274-earth-systems-and-climate-change.

For many, a major goal today is to restore and maintain the carbon cycle. That will be a major undertaking for decades to come. And alongside this concern about restoring the carbon cycle will be a concern about both understanding and maintaining the hydrologic cycle. In the context of long-term concerns about the hydrologic cycle, the need for information and better management goes well beyond the structure of the current legal system to include creating tools for trying to maintain both the human and ecological communities that exist around the hydrologic cycle. Otherwise, we will lose important aspects of life on Earth, and those losses are beginning to occur.

To analyze the current state of the hydrologic cycle in Texas, one might start by comparing water management to the management of the electrical circuit. Today in Texas, we have a smart electrical grid and arguably a dumb water grid as is graphically shown in Figure 2. This is not to say that the folks working in water are not intelligent; they are and they work hard. But the system within which they are working is not smart, not dynamic, not what is needed.

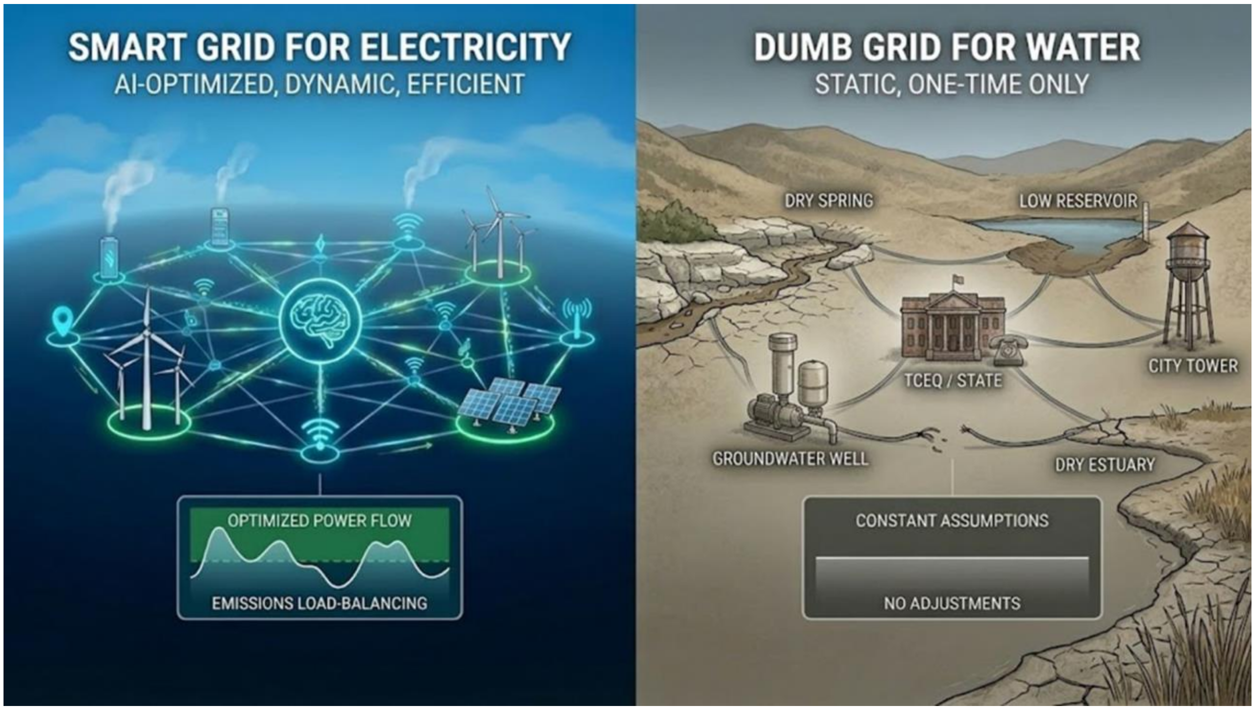

Figure 2. Image comparing the management of the electrical grid to the water grid. Image by EnviroAI

Our water management tools are static rather than dynamic and not based on using the best information available. The drought of the 1950s is used as the standard, but our climate is changing and droughts are getting worse as population growth is depleting groundwater that was basically untapped in the 1950s. There is no direct planning connection between spring flow and water availability on the Hill Country rivers that receive much flow from springs. The permits for water use are based on static assumptions that are no longer applicable. There is no requirement for returning flow to the point of withdrawal. There is looming litigation over keeping endangered species safe. And our bays and estuaries essentially have no right to inflows that are an integral part of the hydrologic cycle.

There is no reason that there cannot be a “smart grid” for water. Indeed, in this paper, we are proposing the creation of a “Watershed Intelligence Engine” that utilizes the best current available information and the best modeling and evaluation tools to provide high quality information to managers and to the public. Essentially, we are proposing the creation of digital twin of the various river watersheds of concern – a tool that addresses the key issues about water availability and ecosystem integrity holistically. This tool is long overdue and would contain the elements set out in Figure 3.

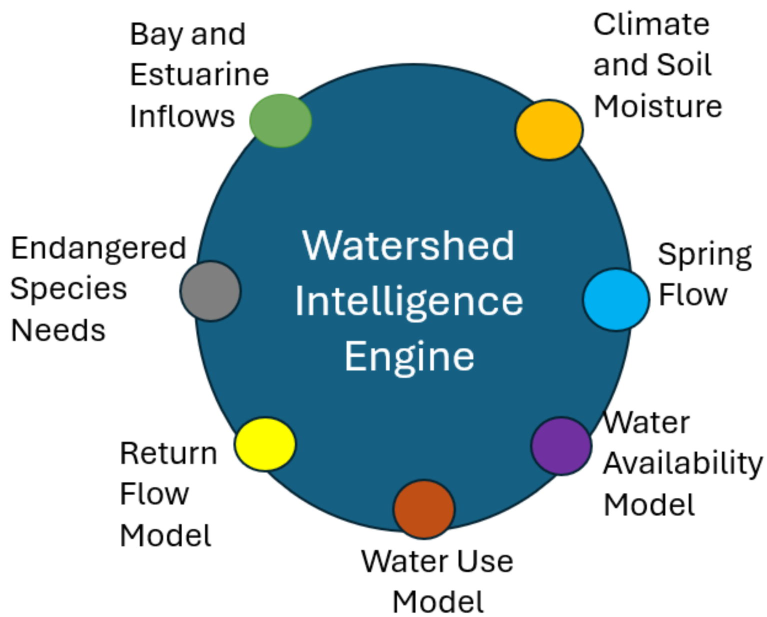

Figure 3. The elements of the Watershed Intelligence Engine (WIE). Image by Jim Blackburn

A Note of Caution

Before doing further, a note of caution is needed. AI is a tool, not an answer in itself. AI can and often does make mistakes. In fact, it makes sense to assume that there will be errors in early versions of the work described in this paper. In this regard, verification and validation of the WIE will be among the most important tasks to be undertaken as the work described in this paper unfolds. No one involved in this work should make premature promises or predictions. This work must be carefully vetted.

On the other hand, this work has the capability to be developed very quickly. Once the basic elements are loaded into the engine, results can be forthcoming in a very short time period. As such, the enginer can be run, errors detected and corrected and then the engine is run again, implementing a concept generally referred to as rapid fast failure. This is a critical element of the creation of an WIE that can be relied upon and is an important limitation that should whet unreasonable expectations.

The Watershed Intelligence Engine

As shown in Figure 3, the Watershed Intelligence Engine (WIE) is a suite of digital tools that combines several different types of measured and modeled information. There is an absolute need for climate information to monitor long-term and short-term changes as well as soil moisture throughout the watershed. There is a need for spring flow observations in real time and groundwater supply and demand. We need to integrate the current Water Availability Model (WAM) and update it with real-time data to better understand the implications and impacts of withdrawal patterns. We need to understand how water is used and where savings can be realized, and we need to monitor return flows to the point of withdrawal or to another system. The requirements of endangered species such as mussels and whooping cranes need to be understood and addressed along with the need for freshwater inflows to our bays and estuaries. All of these observations, models, and forecasts will be included in this tool to provide a comprehensive picture of these dynamic natural and human-altered hydrologic systems.

Climate and Soil Moisture

In Texas, we are shy about public discussions of climate change, but the reality is the climate is changing in ways that affect water. First, there is agreement that our temperature is rising. It is getting hotter, and we need to monitor this increase and try to understand how it relates to water availability. Science also seems clear that we will see greater weather variability in the future, with more severe droughts and more severe flooding rains. To date, exact predictive tools do not exist, but as they become available, they can be integrated in the WIE. We can have up to date information on temperature and rainfall measurements and trends with the best short- and longer-term projections continuously available and updated.

Additionally, we can utilize satellite imagery that can characterize the watershed more accurately from a drought and water supply standpoint. At the least, we should be tracking soil moisture. NASA has placed a soil moisture satellite (SMAP) in orbit, and we have the ability to track soil moisture in real time with SMAP. Soil moisture is a key variable in determining both runoff and infiltration as well as the general health of the watershed. As we learn more about the use of SMAP, this tool will become more important from a predictive standpoint.

Spring Flow

Spring flow is a second major element to be included within the Watershed Intelligence Engine. Spring flow is a key element to the flow in the Texas rivers that originate in the Texas Hill Country. Interestingly, spring flow is not a direct input into the determinations of water availability. Groundwater use is rising throughout Texas and particularly within the Texas Hill Country where population growth has been substantial with additional increases likely from the development of data centers.

Unfortunately, the combination of droughts and groundwater usage has led to major issues surrounding spring flow. Both Jacobs Well in Wimberley and the Upper Spring at Comal Springs have both ceased to flow over the past few years as is shown in Figure 4.

Figure 4. Images showing the absence of flow from the primary spring at Comal Springs in New Braunfels and Jacobs Well in Wimberley.

In order to track spring flow, we need much better data collection and availability. Only about 40 of several thousand springs are monitored. Those spring flows could be continuously uploaded, and it is possible that satellite imagery can be used to track spring flow where monitoring is not currently occurring. More generally, the availability and use of groundwater will likely need to be added to the database, including incorporation of the Groundwater Availability Models (GAM) for the various watersheds. That would include tracking whether desired future conditions are being met or violated within the 16 groundwater management areas (GMAs) within the various watersheds of the state.

Water Availability Model (WAM)

At the center of Texas surface water use and allocation is the Water Availability Model (WAM), a tool developed most recently in the late 1990s and early 2000s. This tool is used extensively by the Texas Commission on Environmental Quality (TCEQ) to determine whether there is water available to be allocated to new permit applicants as well as to monitor and supervise water use and withdrawal by permittees.

There are both strengths and shortcomings to the WAM concept. From a strength standpoint, it represents an important conceptualization of the cumulative relationship of water allocations under various flow conditions. On the other hand, the WAM makes static assumptions – average flows, drought flows – and has no ability to change withdrawals as supply diminishes.

Under the concept of the Watershed Intelligence Engine, the WAM will be interactive, updated daily with new flow data, rainfall amounts and runoff predictions, withdrawal accounting and recommendations for reductions or increases in withdrawal amounts based on keeping the river flowing to the coast with adequate flows to protect bay and estuarine production.

There is no doubt that this approach is different from the approaches that are currently being used to administer surface water use in Texas. And there is the relationship with the legal system to consider which is discussed in the concluding section of this paper. But most importantly, this water availability model will provide accurate information about the situation regarding water availability in real time – information that is not comprehensively available at this time – information that is direly needed for good water management.

In Figure 5, an example of how the interactive WAM might look is set out. This example shows the water rights permits that have been issued for this stretch of the river in yellow with the amounts available with the click of a mouse. The flow data will be up to date and can be contrasted with annual flows that are used for permit issuance purposes. Current information about withdrawals will be available, and projected problems will be identified. And that is just the beginning.

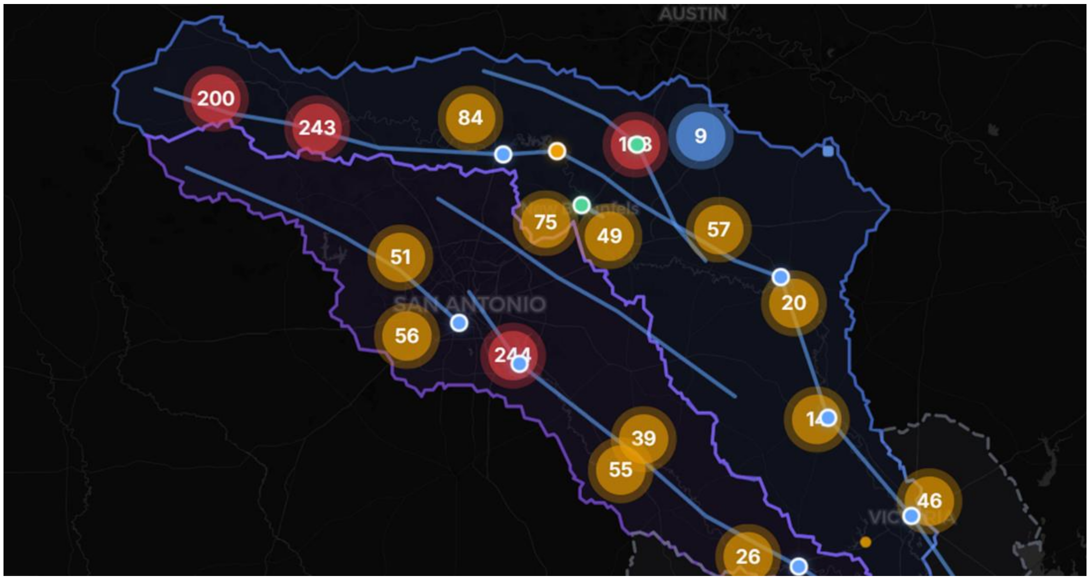

Figure 5. Example of output from beginning stages of the dynamic WAM. Source: EnviroAI

One important piece is removing defunct or unused water rights. According to Carlos Rubenstein, former Rio Grande watermaster and TCEQ commissioner, “the last water rights cancellations in the state were in 2001-2002 on the Rio Grande” which he orchestrated. This needs to be done comprehensively on every river system, and the water intelligence engine will help bring these issues to the forefront to make better informed policy decisions. Former Commissioner Rubenstein also suggested that these cancelled rights could be awarded to the bays and estuaries preserving vital coastal fisheries and ecosystems.

Water Use Model

The water use model keeps up with the distribution and use of water from the river to the user. The users may be agricultural, industrial, or municipal, but their needs to know dynamic water availabilities are shared.

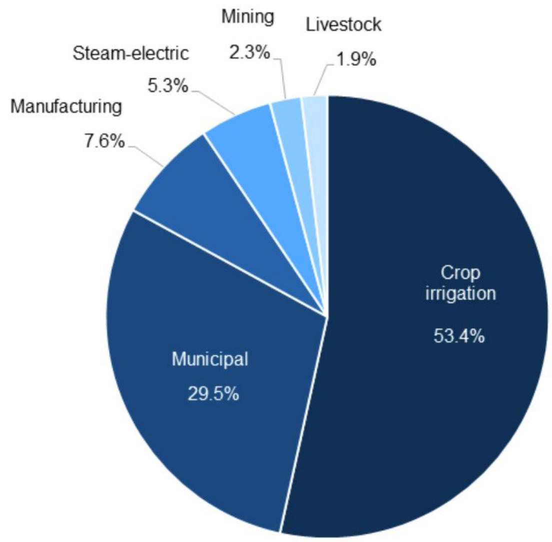

Figure 6. 2020 water use in Texas with agricultural use representing over 50% and municipal representing almost 30%. Source: Water Development Board as prepared by the Federal Reserve Bank of Dallas.

Here, one of the key issues is reducing demand over time. This can be done voluntarily with excellent information. There are ways to work creatively to reduce water use if we better understand the realities of various use patterns and the importance of changes. Currently, there are no excellent tools to keep up with water use through the life cycle of the water supply system. This will be an important tool, as you cannot manage what you do not measure.

Figure 7. Two important water uses of concern – flood irrigation and lawn watering.

It is also interesting to understand the current trends in voluntary action by various corporations. There is currently a movement in the corporate sector toward either net zero or net positive water. This concept of water use seeks to either reduce consumption to where it is equal to or less than the water footprint of a particular site or area prior to development. This is a very interesting phenomenon that fits very nicely within the concept of the power of information. Companies that have made a net zero or net positive water commitment include Amazon, Pepsico, Intel, Microsoft, Meta, Google, Nestle, Starbucks and CocaCola.

There is also a water stewardship initiative that has been created for cities named the C40 Water Safe Cities Initiative. Cities that are participants in this program will try to reduce their vulnerability to flooding and droughts in the period from 2027 to 2030. Information from this initiative can inform efforts to better manage our water in Texas. Cities in the United States that are part of the C40 Water Safe Cities initiative include Los Angeles, New York, New Orleans and Phoenix.

Return Flow Model

Another component of the Watershed Intelligence Engine is the return flow model. Here, the goal is to better understand the pathway of water through the end use and back into the river system. Of concern here is the fact that under Texas law, once water is treated through a wastewater treatment plant, it can be reclaimed from the end of the pipe and reused, thereby never returning to the river or stream.

This situation has not arisen to any great extent in the state so far because most citizens do not see themselves drinking treated wastewater from the end of a pipe from the wastewater treatment plant. However, there are many cities such as Houston that rely on the delivery of treated wastewater from upstream users such as Dallas. And our bays and estuaries also need this treated wastewater to augment the chances of some of that water making it to the coast.

Under the design concept for the WIE, return flows would be monitored and data would be provided in real time if possible regarding the flows coming from various permitted wastewater discharge sources along the waterway. In this manner, a real-time picture could be obtained of both withdrawals and return flows, offering an excellent daily picture of what the river gives and gets back.

There have been some very creative concepts set forth about how to treat return flows. The San Antonio Water System (SAWS) has received a bed and banks water rights permit from the Texas Commission on Environmental Quality to return about 50,000-acre feet of water to the San Antonio River and dedicate it to flow down the river to San Antonio Bay. This is an excellent innovative concept for getting water to San Antonio Bay – water that is needed for bay productivity including blue crabs that are eaten by endangered whooping cranes.

Endangered Species Model

An important issue in water management is the protection of endangered species. Several species of riverine mussels have been designated as endangered by the U.S. Fish and Wildlife Service and must be protected against harm by those who use the water in our streams and rivers. These mussels require minimum flows and certain water quality throughout the year. Similarly, the endangered whooping crane relies on freshwater inflows due to the fact that blue crabs are its primary food source in the winter here on the Texas coast.

Interestingly, the Guadalupe Blanco River Authority is working on a habitat conservation plan with the U.S. Fish and Wildlife Service to develop plants to mitigate potential harm to river mussels found in the Guadalupe River as well for whooping cranes that winter around the Guadalupe River estuary. This HCP is a voluntary initiative undertaken by GBRA to attempt to address potential endangered species issues in the future.

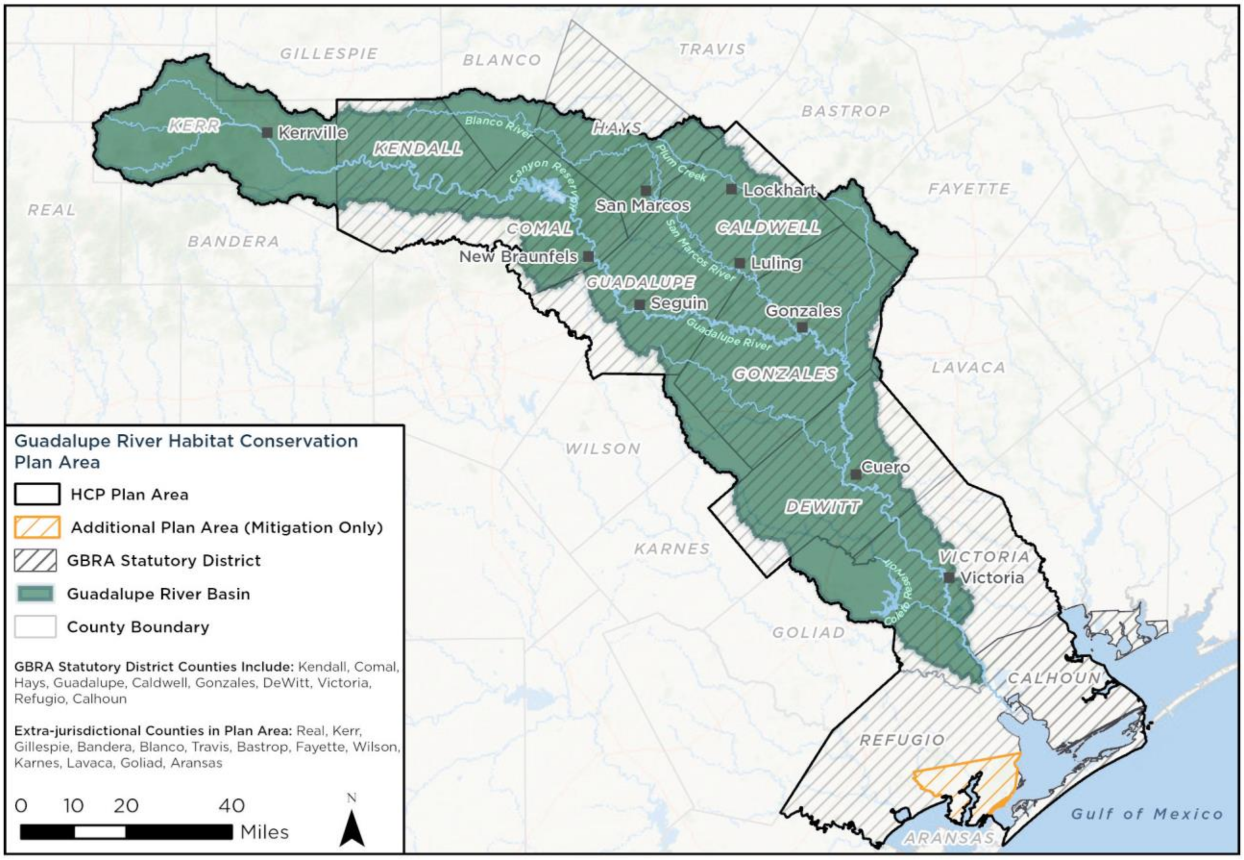

Figure 8. Map showing the extent of the Guadalupe River Habitat Conservation Plan by the GBRA. Map from GBRA.

In both rivers without and with an HCP, real time data will be very important. Short term water flows needed to protect the species can be identified as well as deficiencies in the supply of water in the longer term. These endangered species concerns are relatively recent but will not go away. An effective response can be kindled by the output from the WIE.

Bay and Estuarine Inflow

The final piece of the WIE is the bay and estuarine inflow modeling components. Here, real-time assessments will be made of real-time freshwater inflows to the bay as well as current bay conditions as determined by monitoring systems throughout the bay system. Prior work by the TCEQ has created the study required by Senate Bill 3 (SB3) of most major bay systems on the Texas Coast, and the freshwater inflow needs have been defined. This model will simply report on the condition of the bays and whether or not goals are being met.

Bay productivity is an important part of the water cycle. Water that flows down our rivers fuels the production of our estuaries. Estuaries produce both brown and white shrimp, blue crabs, oysters and our coastal recreation finfish resource. Fishing for speckled trout, redfish and flounder would be significantly reduced without freshwater inflow and as a state, we have not made the commitments to date that are necessary to protect and sustain our coastal fishery.

Figure 9. Estuarine species needing freshwater inflow and nursery areas within the bay.

The WIE will provide the raw information to reveal the health of our estuaries and how we humans are doing on our attempts to bring freshwater inflows to the bays and estuaries. In this situation, there is no doubt that there is power in the daily availability of this information. It can and will happen.

The Watershed Intelligence Engine as a Tool

Once the pieces of the WIE have been assembled, then the work begins on the assembly of the engine. As shown in Figure 7, the WIE is comprised of three distinct steps. Step 1 is the assembly of the data which has been described so far in this paper. Step 2 is the actual engine which works through layers of information to create outputs that are continuously being updated.

And Step 3 creates the outputs which are the intelligence products of the engine.

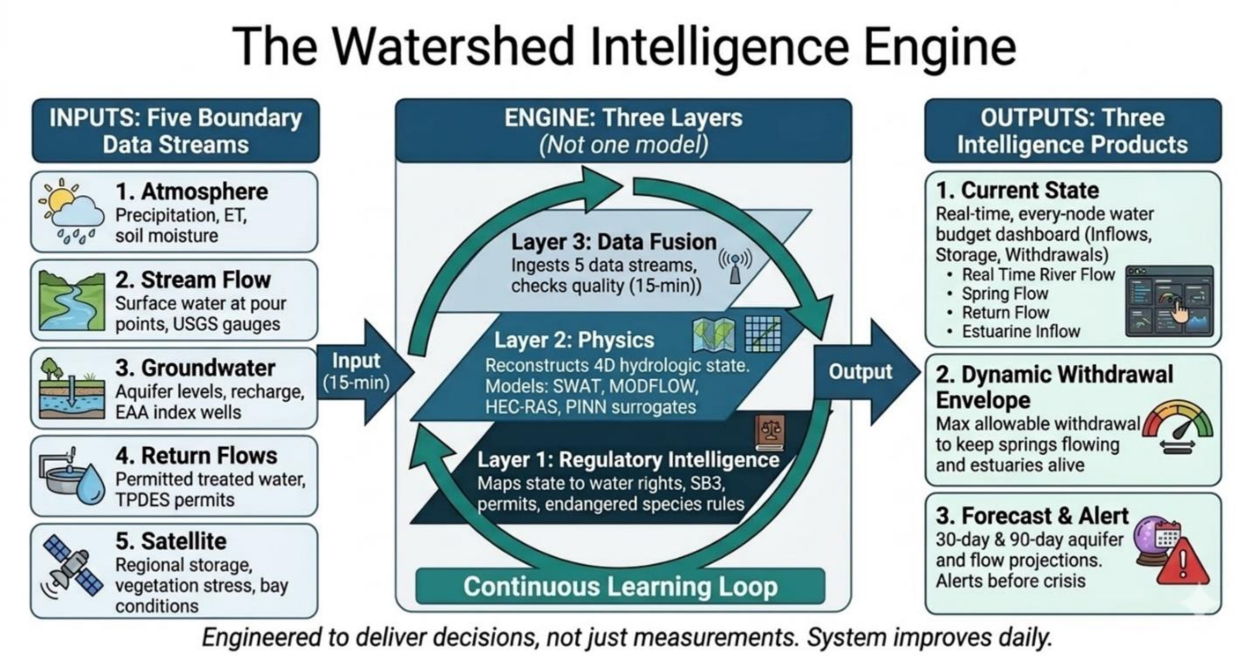

Figure 7. Illustration of the Watershed Intelligence Engine with its three phases of operation. Image from EnviroAI.

As can be seen above, Step 1 is comprised of physical inputs. As shown above, inputs are received from the atmosphere, the stream itself including spring flows, the groundwater monitoring system, return flows and from satellites. There may be more inputs as we get deeper into the development of the WIE.

Step 2 shown above is the actual working engine which is depicted as having three layers, although that also could change as we learn more. Layer 1 is input regarding regulations that affect the variables that are being evaluated. This would include water rights permits, Senate Bill 3 estuarine input findings, wastewater permits and endangered species requirements. Layer 2 is where the physics of the system are evaluated, including reconstruction of riverine flow and the running of various models including the WAM, the soil and water assessment tool (SWAT), mod-flow for groundwater analysis, HEC-RAS for flooding analysis and BBEST for bay and estuarine modeling, among others.

Layer 3 brings in updated observational data into the models, creating the near-real time dynamics needed for adaptive management. These models will be run simultaneously with output re-evaluated in 15-minute intervals where such data is available. Over time, machine learning and other types of interpretations will occur within the engine itself.

Step 3 is the output from running the engine itself. The first output is real-time data regarding spring flow, river flow, withdrawals and returns and freshwater inflows to our bays and estuaries. The second output would be interpretative data about how the river-system is performing relative to norms and needs and recommendations will be made regarding either reductions or potential increases in water usage. The third output would be projections of both drought or flooding – what is coming in the next 30 days and what we might expect within the next 90 days.

And again, it is important to note that the results of the WIE must be validated and verified time and again. An error-plagued result benefits no one.

Interaction With the Legal System

Texas water law has not changed very much in the last 50 to 100 years. Our groundwater is controlled by the concept of the rule of capture which dates back to the *East* decision in 1904 where the Texas Supreme Court mentioned that groundwater was not susceptible to management due to the use of the "occult", referring to the use of water witches to find groundwater. Now that is ancient thinking.

Our surface water laws are based on concepts and permits dating back to before 1900. Our rather mixed system of riparian and appropriative rights was combined in a series of hearings/lawsuits that occurred in early 1960s when most modern water rights were issued by the state, marking our transition to a fully appropriative rights system. That system is based on a first in time, first in right system that gives priority to uses that may no longer be a priority from a public or economic interest standpoint.

It will be up to the Texas Legislature, the Texas Water Development Board, and the Texas Commission on Environmental Quality to determine how this water intelligence engine becomes integrated into the Texas legal system. We are living in an age where voluntary actions take shape when government fails to act. At the least, this water intelligence engine will have a great effect on individual water users – their thinking and their responses to the challenge of managing water so that the function of the hydrologic cycle is not destroyed which could certainly happen if we don't get smart about our water use.

Conclusion

There are rules that control human action but have not been passed or decided by any governmental authority. These are the rules by which the Earth operates, otherwise referred to in this paper as Earth Rules. An interesting question is how do these Earth Rules fit into the human system of laws and regulations?

Earth Rules are set by nature and understood through science. We have the laws of physics. We know that gravity exists. We don't need to write that law down, but we discover it when we humans leave our footing behind and try to stay up in the air. It simply does not work. And interestingly, there is a legal system that is based upon fundamental rights and knowledge called natural law. And it is very germane to this conversation about Earth Rules.

Natural law is law created from human reason – from our thought processes rather than from the decision by any country or governing body. In that sense, this legal system is beyond the reach of individual countries or English common law or Spanish civil law or the Sharia legal system or other legal systems. Natural law is a higher authority, based on human reasoning – based on science.

Natural law dates back to Aristotle who spoke of a common law according to nature that should guide man-made laws. Historically, natural law has been linked to morals and ethics that are beyond what is called "positive law", also known as human law. Natural law is cited as a basis for the Declaration of Independence including the inclusion of "unalienable rights" as a basis for the formation of a nation. These unalienable rights are rights beyond the reach of human laws. They are fundamental – basic to all of us.

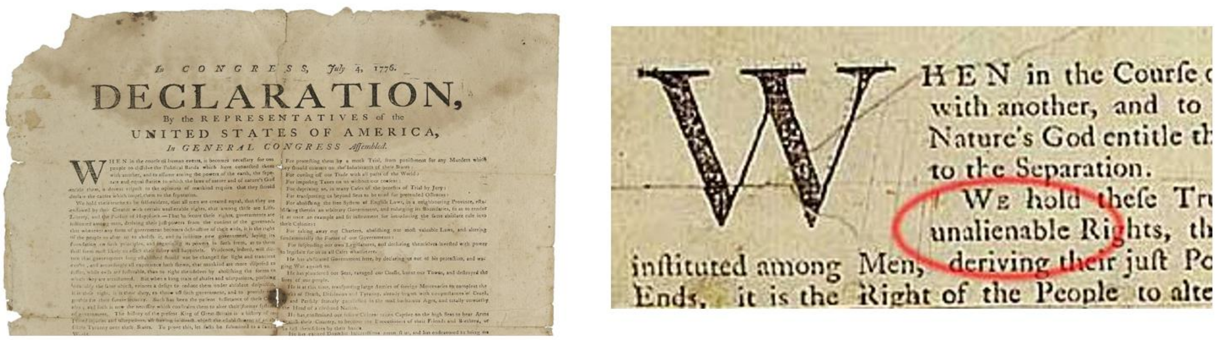

Figure 10. Excerpt from the Declaration of Independence.

Natural law is law that is just and serves the common good. It has a moral and ethical basis. It is based on human reasoning and knowledge. To date, natural law has not been linked to fundamental principles about the functioning of the Earth. As we learn more about ecology and Earth Rules, it seems reasonable that these truths about how the Earth functions should fall within the province of natural law.

Given the unique convergence of Earth Rules and natural law, it is reasonable to ask where might these concepts find acceptance and be adopted? And it is here that the Water Intelligence Engine will emerge as tool of importance – our guide to compliance with our hydrologic Earth Rule.

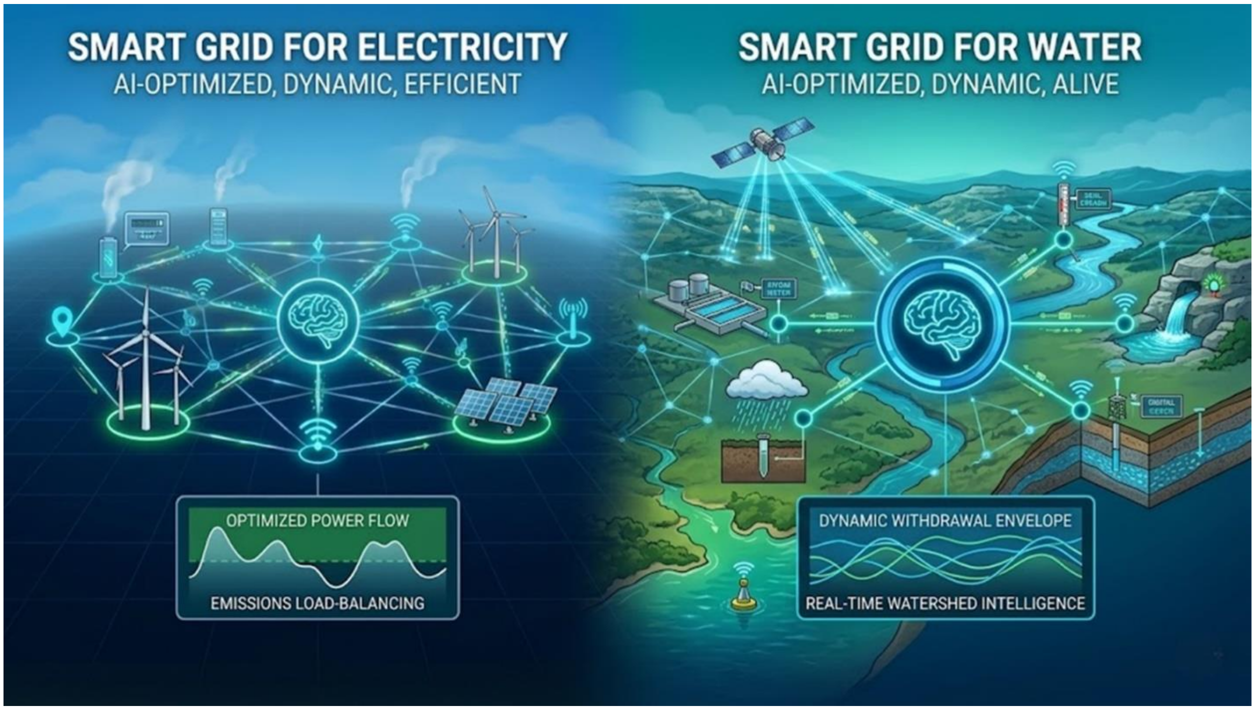

Figure 11. Texas with both a smart electrical and smart water grid. Image from Enviro AI

In summary, Texas can have both a smart electric grid and a smart water grid. We just need to do it.