

## 2009 Gila Science Forum

Global Resources Center Auditorium, Western New Mexico University, Silver City, NM

June 3, 2009, 8:00 am to 5:00 pm

### Notes<sup>1</sup>

#### FORUM PANELISTS

Please see the Appendix for biographical information about the panelists.

Dr. William Fagan, Ecology, University of Maryland

Dr. Keith Gido, Aquatic Ecology, Kansas State University

Dr. Robert Glass, Hydrology, Sandia National Laboratory

Dr. Paul Marsh, Aquatic Ecology, Marsh & Associates

Dr. Waite Osterkamp, Geomorphology, U.S. Geological Survey

Dr. Ron Ryel, Biostatistics, Utah State University

#### FORUM INTRODUCTION AND STRUCTURE

Mary Orton (MO): In 2004, Congress passed the Arizona Water Settlements Act, which provides the potential for New Mexico to develop an additional 14 thousand acre-feet (KAF) per year of Gila River water. It also provides the potential for \$66 million to \$128 million in federal funds for development. There are numerous restrictions on the use of the water and the funds.

By 2014, New Mexico must give notice to the Secretary of the Interior how, or if, New Mexico wishes to utilize its benefits under the Act. The direction from the Governor is to use the best available science, coupled with a full and inclusive public involvement process, to both protect the unique and valuable ecology of the Gila Basin and to provide for present and future water needs.

An important step in the decision-making process is to determine the potential effects of flow modification on the aquatic and riparian resources of the Gila River. The 2009 Gila Science Forum is designed to aid in that step.

Our purpose today is to identify, discuss, and recommend:

1. Ways of determining the potential effects of flow modification on aquatic and riparian resources of the Gila River (including risks and uncertainty), and
2. How information gleaned from such efforts might be integrated to provide an ecosystem-based assessment of effects

Today's forum is a logical extension of the 2006 Gila Science Forum, which provided an overview of critical questions and information needs as well as providing broad recommendations for an integrated investigative framework to address questions and needs.

---

<sup>1</sup> The Forum was facilitated by The Mary Orton Company, LLC (TMOC), which was also responsible for taking detailed notes during the Forum and producing this report. These notes are not verbatim. They were lightly edited by TMOC for readability, and panelists were invited to make any additions or corrections they wished.

Today, we hope to move beyond the broad questions and approaches of the 2006 Forum, and get to the specifics of filling critical informational needs, selecting appropriate tools and methods to assess effects of flow modification, and integrating these into an accessible and functional guide for aiding citizens of Southwestern New Mexico in their effort to determine if and how additional water development might occur in the Gila and San Francisco rivers.

The panel of distinguished scientists will have a conversation among themselves today with regard to the four questions they have been posed. Their bios are in your packets, and they will introduce themselves in a moment, followed by an overview of the natural history of the Gila River by Rich Valdez.

As you see in the Overview in your packets, the Forum is organized around four questions.

1. In broad and general terms, what are the potential effects of flow modification on the biological, hydrological, and geomorphological attributes of southwestern rivers?
2. What tools and methods are available to assess the biological, hydrological, and geomorphological responses of a river to human-induced flow modification? What are the advantages and disadvantages, risks and uncertainties associated with each tool and method?
3. How might information obtained from biological, hydrological, and geomorphological studies be best assimilated and integrated to understand the effects of flow modification on ecosystem function?
4. Recognizing that time and resources are limited (to about one year and \$1 million), what are the most pressing tasks (including, potentially, filling information gaps) that we need to address in order to assess the effects of modified flows on aquatic resources of Gila River?

The panelists will discuss each question. After a summary of key points, audience members will have an opportunity to ask questions in writing on the 3x5 cards you received at registration. I will choose the questions to ask. I am assuming we will not get to all the questions, and I apologize in advance for that. I will try to choose questions that seem to be representative of all the questions I receive.

My assistant, Lea Galaz, will take notes during the Forum, and her notes are being projected on the screen in front of you so that you can follow along.

Lea will ask for an explanation for words she does not understand. I have asked the panelists to take that as a cue to explain it to everyone. In addition, feel free to bring up a 3x5 card to me with the word on it if you do not understand something. There are more 3x5 cards at registration.

Tomorrow, the panelists will meet in private to write up the results of today's Forum. Lea and I will assist them. As they begin their work, we will give them all the questions you write on 3x5 cards, even those we do not have time to ask. They hope to have the report completed by the end of the month, and it will be made available on the stakeholders' web site and at subsequent Gila Stakeholders Group meetings.

Thanks to Henry Messing and Terra Manasco for handling registration, to Russ MacRae for managing the PowerPoint presentations, to Lea Galaz for her able assistance with Forum outreach and logistics, and to the planning committee for Forum process design: Dave Cowley, Mike Harvey, Russ MacRae, Terra Manasco, Henry Messing, David Propst, Craig Roepke, and Rich Valdez.

Thanks, also, to the people who gave presentations during yesterday's tour, which helped the panelists familiarize themselves with the Gila River: Topper Thorpe and Dave Ogilvy (farmers and ranchers in the area), Martha Schumann (The Nature Conservancy) and Art Telles and Andrea Martinez (U.S. Forest Service).

(The panelists introduced themselves. Please see the Appendix for the panelists' bios that were included in the registration packets.)

### OVERVIEW OF GILA RIVER NATURAL HISTORY

Rich Valdez: Good morning, I am Rich Valdez, a fish biologist. I work for SWCA, a consulting firm, and I represent the Interstate Stream Commission on the Forum planning team. I live in Logan, Utah. I have a deep and sincere love of the Gila River. I was born and raised in Anthem, New Mexico. My dad and I used to hunt and fish in the area, and we had many wonderful times.

Why are we here? We have asked the panel to consider and evaluate an array of tools and methods to assess the effects of flow modification. We want to learn how best to approach evaluating flow modification. We also hope to determine how this information can be integrated. The goal is to recommend actions to implement New Mexico's portion of the 2004 Arizona Water Settlements Act (AWASH).

It is important to remember that as the AWASH is implemented, Governor Bill Richardson gave the following direction:

1. Use the best science available. This is the basis for the 2006 Forum and today's Forum.
2. Provide for full public involvement, full and open disclosure.
3. Protect the unique and valuable ecology of Gila River basin, maintain a balance, maintain the system.
4. Provide for present and future water needs.

(PowerPoint presentation.) I would like to kick off some thoughts about ecological processes today. The Gila River is one of the most important rivers in New Mexico and Arizona. Many of you use it, live on it, or live near it. It provides water for agriculture, recreation, commercial, and domestic uses.

The Gila is a major tributary of the Colorado River, which it joins at Yuma, Arizona. The Gila River originates in the Black Range of western New Mexico at an elevation of about 10,000 feet. It flows for about 650 miles and drops about 9,750 feet. It is the second largest tributary of the Colorado River with native flow of over 6,000 cubic feet per second (cfs), second only to the Green River. It is largely free flowing through New Mexico and into Arizona, and the only mainstem dam is Coolidge Dam, southeast of Globe, AZ, that backs up San Carlos Reservoir. There is great human demand on the Gila River and in late summer it is usually dry or a trickle just downstream of Phoenix. Major tributaries include the San Francisco, San Pedro, Salt/Verde, and Agua Fria.

In New Mexico, the Gila River is made up of the east fork, middle fork, west fork, Mogollon Creek, and Sapillo Creek. The headwaters of the Gila River originate in the Gila National Forest from the Black Range in the east and the Mogollon Mountains in the northwest. Most of the upper watershed is within the Gila and Aldo Leopold Wilderness areas. Small reservoirs are located on these branches, including Snow Lake on the middle fork, Wall Lake on the main fork, and Lake Roberts on Sapillo Creek. Most of the forested upper watershed is in federal ownership where human use is largely confined to low-impact outdoor recreation, dispersed cattle grazing, and sparse human settlement. In the downstream valley reaches, human influences are greater, but limited to seasonal water diversion for small tracts of irrigated agriculture, livestock grazing, and a few scattered dwellings. An approximately 10-mile reach of the Gila River below Cliff, known as the Middle Box and Lower Box, cuts through steep canyons and provides whitewater recreation.

The Gila River in the Wilderness Areas is difficult to access with steep surrounding terrain and dense riparian vegetation. The Middle Fork of the Gila River flows through deeply incised picturesque

canyons. The riparian corridor is well defined and is surrounded by dense vegetation and semi-arid forests of Ponderosa Pine. Human impact is low and water quality is high. In the upper reaches, the Middle Fork cuts through steep canyons with a typical habitat of pools, riffles, and runs. The Gila River from Mogollon Creek to the Arizona state line is a vital stretch of river for a host of agricultural, domestic, and recreational water uses within the state of New Mexico. This 60-mile reach of river is also home to some very valuable wildlife species. From Mogollon Cr. through Cliff-Gila, the river meanders through an open alluvial valley. The riparian corridor is well developed with a gallery of cottonwood trees and willows. Large piles of wood debris are reminders that the Gila River can deliver highly variable flows from just a few cubic feet per second to 34,000 cubic feet per second.

Throughout the Gila River in NM, there is abundant evidence of highly variable flows. High springs flows from snowmelt and high flows from late summer monsoonal rainstorms help to maintain the cottonwood gallery and riparian corridor and to maintain river channel diversity, which are important to all forms of wildlife and fish.

Throughout much of the valley, the river maintains its original meander and historic riparian and instream habitat. A cottonwood/willow gallery is prominent and the stream is a series of cobble/gravel riffles and deep pools with large deposits of woody debris.

Downstream from Cliff, the Gila River enters a small narrow gorge known as the Middle Box. The gradient of the stream steepens and the channel becomes more confined. The Gila River through the boxes is a popular for whitewater rafting, kayaking, and canoeing. Downstream of the Middle Box is the Lower Box, which is narrow canyon with a confined river channel and relative high gradient. The Gila River leaves the state of New Mexico near Virden at an elevation of about 1,140 feet. Turbidity can vary as late summer monsoonal rainstorms and flooding can transport large amounts of sediment.

In places, these high flows cause the river to meander and damage roadways and bridges. Here is the West Fork of the Gila River after flooding in January 2005 damaged the highway and following repairs. It is a dynamic river, and this damage is evidence of that.

The gradient of the Gila River below Mogollon Creek is generally less than 0.10% (about 5 ft/mi). Through the Middle and Lower Boxes, gradient nearly doubles to about 0.19% (about 10 ft/mi).

Flow of the Gila River is highly variable, as indicated by a 75-year period of record for the USGS gage near Redrock. Average recorded flow is 216 cubic feet per second, minimum is 3 cfs, and maximum is 34,000 cfs. Flow of the river is highly variable as to magnitude, but also time of year.

High flows of the Gila River originate from winter storms and snowmelt runoff early in the year, or from monsoonal rainstorms in late summer. The time of year when high flows occur can vary dramatically, as seen in this hydrograph of three recent years, 2005, 2006, and 2007. In 2005, high flows of 12,600 cfs occurred in mid-February, whereas high flows of 6,180 cfs in 2006 occurred in late August. In 2007, there was low snowmelt runoff, little monsoonal rainstorm activity, and only some winter precipitation.

Eight species of fish are native to the Gila River in New Mexico. The Gila trout is also native, but occurs in higher elevation streams. Six of the eight species are cyprinids or minnows and two are suckers. The loach minnow and the spikedace are each listed as “threatened” under the Endangered Species Act. Critical habitat is designated as portions of the East Fork, West For, and Middle Fork, as well as the upper Gila River from Moore Canyon (near the NM/AZ line) upstream to the confluence of the East and West forks. On May 3, 2006, the Service published a 12-month finding that listing was warranted for the headwater chub, but precluded by higher priority listing actions. The U.S. Fish and Wildlife Service is currently conducting a “status review” of the roundtail chub (also known as the Verde trout) in the Lower Colorado River Basin with a determination due June 30, 2009.

My dad and I used to hike up to the middle fork and catch beautiful trout before the Endangered Species Act was passed. I came to find out they were listed later, but they were good. We used to call the fish at the bottom the Gila trout; however, it is actually a roundtail chub. It is easy to confuse the two because of similar body shape and a deep orange belly color.

Fourteen species of fish occur in the upper Gila River; these have been introduced from other river basins. These include familiar game species like channel catfish, largemouth bass, smallmouth bass, brown trout, and rainbow trout, as well as small minnows like red shiner, fathead minnow, and mosquitofish. Many of these species are predators and competitors of native fish species.

The endangered Colorado pikeminnow and razorback sucker were found historically in lower reaches of the Gila River and have been reintroduced recently into the Salt and Verde rivers in Arizona.

Two bird species are of special concern in the Upper Gila River. The yellow-billed cuckoo is a federal candidate species that is a seasonal migrant occupying the riparian corridor along the stream. The southwestern willow flycatcher (SWFL) is a federally endangered species. In 2001, private lands hosted 50% of the territories of SWFL, including one of the largest known populations in the Cliff-Gila Valley. Four distinct southwestern willow flycatcher critical habitat segments are designated along the Upper Gila River from the Turkey Creek/Gila River confluence downstream to San Carlos Apache Tribal Land, AZ. Critical habitat extends from Turkey Creek to the upstream entrance of the middle Gila Box, except for property owned by the U-Bar Ranch. Another reach extends from Red Rock downstream to the town of Duncan, Arizona. Southwestern willow flycatcher in the Cliff-Gila Valley uniquely nest in boxelder trees, with highest density in the U-Bar Ranch. The Service has an agreement with the U-Bar Ranch under a Conservation Plan.

There almost 250 different species of birds. In addition, there are raptors, neotropical forms, reptiles, amphibians, and mammals. It is a diverse system and a sporadic one.

The Upper Gila River is one of the few free-flowing rivers in the west. Maintaining a balance between ecological integrity and human uses is a challenge that faces all of us—and one that this workshop will help to meet. There are four fundamental guiding principles proposed by Lloyd that serve to remind us of basic ecological concepts.

1. Flow is a major determinant of physical stream habitat.
2. Aquatic species have evolved life history strategies in response to flow.
3. Maintaining natural connectivity is essential to riverine species.
4. Invasion and success of exotic species in rivers is facilitated by flow regime alteration.

Thank you for the opportunity to talk to you about this system and give you some perspective. I enjoy being here; I have not been in Silver City since a high school football in which I broke my arm.

**QUESTION #1: IN BROAD AND GENERAL TERMS, WHAT ARE THE POTENTIAL EFFECTS OF FLOW MODIFICATION ON THE BIOLOGICAL, HYDROLOGICAL, AND GEOMORPHOLOGICAL ATTRIBUTES OF THE GILA RIVER?**

Waite Osterkamp (WO): In broad terms, this opens up Pandora's Box. I would reword the question so that it reads "hydrology, geomorphology, and biological attributes." Hydrology affects everything. This is expressed by this equation (reference to slide) that includes width, roughness, and median-particle size; they are all functions of discharges of water and sediment. Everything depends on these two fluxes. Landforms are determined by these two individual variables. Also important is the concept that everything is dependent on the water budget, or water balance equation. Precipitation determines the amount of water available to the Gila. Outflow represents the stream flow of the Gila River.

Finally, I want to make a fundamental point: when we look at a system or at a particular site, we are often thinking that we can tell what the processes are going to be. Processes determine the attributes of the landform but bottomland features do not define processes. This is a basic misconception.

Bob Glass (BG): Most of my comments summarize some of the work from the last forum (in 2006) and they come with Stuart Bunn's influence. The slide shows an adaptation of a figure adapted from Bunn & Arthington (2002) *Environmental Management* 30, 492-507.

Principle 1: Temporal and spatial structure of flow determines the physical habitat, water quality, and ecosystem composition and diversity.

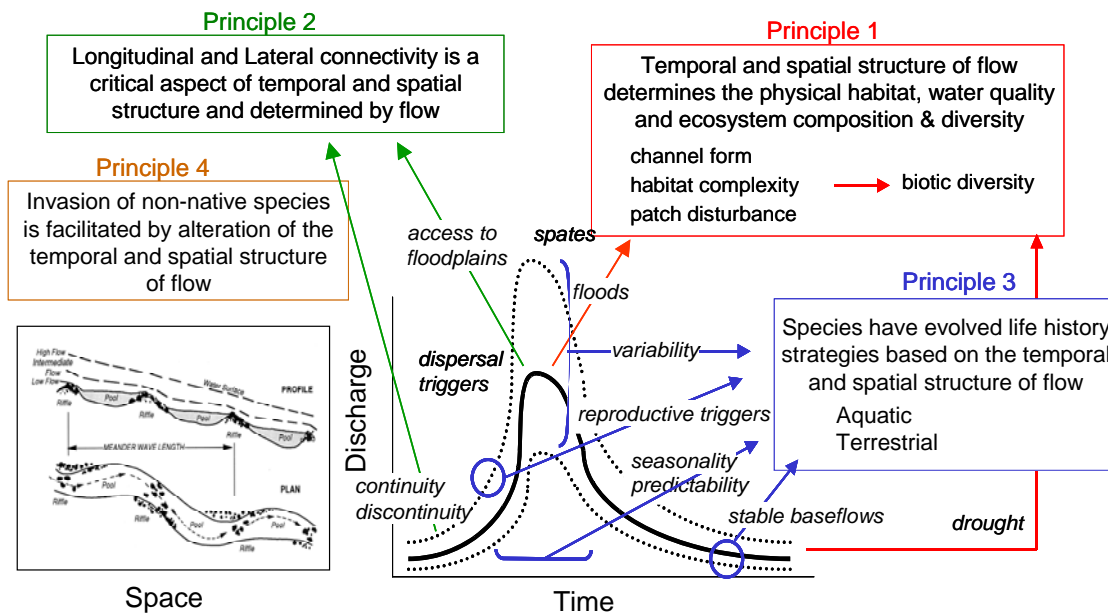
Principle 2: Longitudinal and lateral connectivity is a critical aspect of temporal and spatial structure and determined by flow.

Principle 3: Species have evolved life history strategies based on the temporal and spatial structure of flow.

Principle 4: Invasion of non-native species is facilitated by alteration of the temporal and spatial structure of flow. How water moves through channels: connectivity in time and space (structure) influences the biology and how things erode. That is structure.

### Potential Effects of Flow Modification, RJ Glass #1

## Temporal and Spatial Structure of Flow is Critical



\* Adapted from Bunn & Arthington (2002) *Environmental Management* 30, 492-507.

Keith Gido (KG): There is a naturally functioning ecosystem in Gila-Cliff Valley. These species of federal concern are stable and their population goes up and down. The current management has maintained these species. However, the scientific literature clearly shows that reduced flows are at the expense of fish. This shows up in large systems like the San Juan and the Gila River during drought years, where we see smaller populations and fragmented populations. When you reduce flows, the abundant species decline. We know high flows are good, but the mechanisms are uncertain.

Fragmentation due to low flow or timing of flow can disturb reproduction. Altering flow regimes can disturb or affect available habitat.

Bill Fagan (BF): I am a spatial ecologist. If you change the nature of flow, you can alter the pattern of connectivity. The system is connected in terms of water, sub-surface flow, or through riparian vegetation that facilitates animal movement. Flow influences this connectivity. The pattern of connectivity can change with alteration of flow regimes. Using a database of Sonoran Desert fishes, in collaboration with W.L. Minckley, a professor at Arizona State, I was able to establish this relationship. The point is that as you change the level of connectivity in a system, some species are more fragmented than others, and those species are more likely to see local extirpations.

Ron Ryel (RR): These are some broad questions. There has been some good discussion, but step back and look at potential effects of flow modification in the system. There will be effects, but the importance is based on what we can do to mitigate these effects, flow or non-flow. Keep in mind the kinds of things that we can do to offset effects. The second thing is to understand the current state of the system. If it is already perturbed, then modification can have more importance. Otherwise, if it is not already perturbed, it may be more resilient to change. Another element to bring back is the evolutionary legacy of the species in the system. These species are going to expect certain behaviors to be able to carry out their life history. We do not necessarily know what those are. Trying to maintain ecological integrity is important, but we may not know what the elements are.

Paul Marsh (PM): I think this implies that any flow modification will have an effect on aquatic biology. Effects can be severe, such as elimination of aquatic fauna if the stream were desiccated. Fish can only survive a few minutes without water. A less severe effect is the elimination of only certain species. The effect could also be changes in abundance or a rearrangement of structure in the community. Even more subtle could be changes in life functions of individuals' health, growth rate, or reproduction. This can be due to habitat changes from changes in flow. Depending on the nature of the flow modification, a stream can become less or more hospitable to native or non-native species. The problem is that many non-natives can reduce or eliminate native species. The bottom line is that the nature of the effects of flow modification depends on the nature of the flow modification itself, including its timing. These need to be carefully defined and described before effects can be predictable or estimated. They also may not be predictable on any level.

KG: Stuart's work might be a springboard for the mechanism at which flows influence biology. I guess one issue of concern is connectivity. I think some of the data from the Gila River and from Bill Fagan shows that these populations are quite variable; they are often rescued by another population. So if spikedace disappear at Iron Bridge, a population at the lower Bird Area could rescue that population.

WO: In that sense, I would like to bring things back to the basics of the first question. I think an important point is that this upper reach of the Gila River has been characterized as very dynamic. It is a very active and high-energy fluvial system. If we talk about connectivity, then it has to be acknowledged how dynamic this system is. This is a system in which the bottomland features are changing on maybe not quite an annual basis, but pretty close. If we are going to look at the biological population in some detail, it has to be in the context of a highly variable landscape.

RR: Another element with connectivity is there is a connection between uplands and riparian zones. This has to do with sediment inputs. The regeneration of plants in the riparian zone is affected by flows, sediment inputs, and geomorphic processes. We have many places where cottonwoods are disappearing because we do not have dynamic flows and related processes. We have to look beyond river connectivity to recognize that these flows set the stage for the regeneration of riparian systems. They are important for the creation of cover for some fish species.

PM: Connectivity is important for the groundwater system. If you put in wells, you are pulling water from streams. The second thing, connectivity for modification is not just about water flows, like pulling water from the river, but also water quality. Water quality includes chemistry, and with flow modification you get different chemistry. There is quite a bit there in terms of modification, not just taking water out of the stream. Changes can modify flow regimes including the watershed and influence the biotic community.

BF: Many of the sensitive species discussed will respond to different kinds of connectivity. Flow modification may affect certain species, and other characteristics might affect other species. There are different spatial scales from which to measure depending on the hydrological processes of concern. Good quality habitat for a certain species may move downstream next year. This can change over time due to flow regimes. Thinking of connectivity as a static metric can only go so far. Quality changes quite quickly. Connectivity has to be a fluid concept as well.

KG: Looking at the graph, let us focus on river channel connectivity, and the importance of multiple populations being connected. There is a lot of variability in the species. Minus three means that the species was not captured. The blue line represents loach minnow so you can see they were not caught, but it recovered and showed up again. The green line is spikedace and it was not captured in this time period but it recovered later. Longfin dace is a black line. This shows clearly that species at a site can disappear, and they are dependent on another location to recover that. This is a table by Miller. What I highlighted in the red square is the numbers of spikedace and loach minnow caught from 1999 and 2005. They persisted at Fred's place. In 2003, they disappeared at Iron Gate Bridge, but occurred somewhere else. It is very important to maintain these different areas, not just in the Gila-Cliff valley but also in the upper Gila area.

PM: There is a lot of connectivity when we look at the Gila Basin in Arizona. Those populations are gone. The reason state and federal governments designate species as endangered is because they have disappeared in a certain range. The datasets are long term in the context of our lifetimes. There are so few of these for western systems. In the big picture, these are short-term data. Long-term effects go way beyond our vision of time.

BG: If you have a system-spanning event, such as a long-term drought that spans this river network, then there is nowhere from which to repopulate the affected species, because it has been wiped clean. It is about both time and space. One of many things on my mind is climate change. General Circulation Models (GCMs) suggest it will get warmer here and that winter precipitation and summer precipitation will be the same or go down or up, but there will be less snow. The flow in the streams may be lower. On the scale of the Gila River, it will be difficult, long-term perturbations. System-spanning events can cause a change in the system's state such that it does not return to where it was.

BF: (slide reference) On the issue of space and time: In some cases, we do have data available over longer time spans than 20 years of the research life of an individual. This represents the collection of 140-160 years of data for fish in the lower Colorado River basin. The issue of spatial and temporal dynamics comes to the front. The y-axis is the probability of local extirpation, which can be defined on 5 m of reach or 100 km of watershed. The x-axis is a measure of how fragmented the species were prior to 1960. What you see is a positive relationship in both. The more fragmented a species distribution historically, the more likely the probability of extirpation over a subsequent 20-year time period. This is unlike the Iron Bridge scenario where a population might be re-colonized by another population. We are talking about a site where repopulation might not be possible on 5 km or 100 km scale. How fragmented the species was historically is related to the likelihood of observing extirpations. We want to look at how strong on a 100-km scale, but on the 5-km scale, you have a lot more variability. There is a strong relationship of connectivity on the 100-km scale, and local scale changes

can compound. However, when you have large-scale changes like regional drought or water withdrawal, then you see long-term periods where there is no re-colonization. There are also larger time and space scales involved.

WO: I think this is beginning to get to the crux of the problem with consideration of different scales, temporal and spatial. Whatever Governor Richardson's intent was, flow modification might have been a politically correct way of saying "we want to put in structures and take water out of the Gila River." This includes scientific considerations and political considerations. It is worth to keep in mind, when we are talking about changes in flow regimes, that there was a period prior to European development when the Gila River was a continuous stream all the way to the Colorado River. Now there is some linear reach of the Gila River that goes from intermittent to ephemeral. With further extractions, that specific reach is likely to change. So then a longer reach would be ephemeral rather than intermittent. If we want to talk about connectivity or perpetuity then we have to be prepared for what the hydrological changes are.

RR: One important consideration is, what are the resources, ecological, and political values that are important in this system? Flow modification will affect the system. Will it be exactly the same as prior to human intervention? This does not mean it will not be functioning, and have high value to a variety of interests. There will be changes, but keep in mind the values. This is where we have to go. Going back to before humans is not an option at this point. It is important to recognize how we can work in this system to meet our priorities.

KG: The main question is, what are the effects of flow modification? As for connectivity, it is no longer connected to the lower Gila. This suggests that it cannot withstand as much perturbation as it once could. This particular system is functioning naturally right now; however, it has some perturbations, so we have to be cautious about pushing it over the edge. It may not be able to recover; it has broken off from its historic network.

RR: To follow up, the resilience of this system is an important issue. If it is not resilient, we will lose or have changes. Lower ecological resilience reduces the ability to have flow modification without strongly affecting the system. One could explore options such as attempting to make the system more resilient before flow modification, or engaging in management that can help increase resilience. Consider actions that can be taken with the landscape or non-native fish that can make the system more resilient to the perturbations that would occur with additional water development.

BG: It might be helpful to think of the system as one that is modified and always will be. It is something we must recognize. We do not understand influences in the context of an un-modified system. We have to recognize this is a complex adaptive system. We do not know much about it, but it will adapt to whatever is done to it. Humans go in and modify, and then study the response. These are not normal, well-controlled experiments. But if we studied everything as we did it, they can be seen as experiments; however, there has to be monitoring of effects. That way if there were change, we could get that information and discover what connects to what, such as interactions between vegetation and fluvial structures. The one thing we can do is make certain we have eyes and ears open and we are monitoring.

RR: This is an important element, and it leads into other three questions. One of the challenges is, we have one river. We like to have experimental controls and treatment blocks; we would like to have five Gila Rivers that we can experiment with and see what happens. We have one river, we already modified it, and we are dealing with factors of climate, precipitation, and temperatures. It makes it more challenging. Monitoring what happens and being reactive to those trends will be important to the process. Somehow, monies for monitoring often disappear. To effectively manage the system, monitoring will have to be built in.

KG: I like the idea of changes in land use that would increase flow and mitigate losses. The chronology of those events is important; there is a high degree of uncertainty in how the system would respond. See if land modification has an effect on flow before you extract flows. The thing to consider is chronology. We need to make sure management options have the effects they are supposed to have before we do them.

WO: There could be changes in the watershed to alter runoff. Earlier I showed a slide of an equation representing a water budget. Evapotranspiration is an important determinant of surface water. With certain practices, we might be able to alter evapotranspiration. I do not know whether these approaches are realistic, but they are worthy of consideration.

BF: An interesting but unrecognized side point is watershed influences on flow. The feasibility of manipulating watersheds to influence flow depends on having large blocs of landscape that can be managed in units. In situations where a group of landowners collectively manages a resource, you can work with a few people to get where you want to go for change in a watershed. If the landscape is in small parcels with diverse ownership, you will have a hard time doing watershed experiments. Having large parcels, farmers or ranchers with large blocs of land, can be helpful. You can ask for these kinds of experimental landscape changes.

RR: Fragmentation is a real problem. In northern Utah, they had problems with loss of diversity in plant communities. Their response was to form a group of ranchers who combined their allotments to manage on a large scale. They could restore functionality in the system, and improve grazing, but only through combining their allotments. A small breakdown among owners can be difficult.

### Key Points

- BF: Connectivity means different things to different species. Conceptually it is a nice term, but there is a lot of variability. It is not a monolithic topic.
- WO: A more specific concept than some others. The most important aspects of the discussion: recognition that perennial streams of semi-arid surface water are very dynamic fluid systems. Fortunately, the Gila River is still in good shape. The amount of water quality, damage is minimal at this point. Assert the large importance of considering scales of time and space. If we do not do that, we box ourselves in and can fail dramatically.
- PM: Things are in good shape. Biologically there is damage, including contamination with non-native species. Not a lot of predictability and the situation can further deteriorate. Summary: General agreement is that if you modify a flow on the upper Gila there will be effects, both biological and hydrological, on multiple scales over time and space.
- KG: Native fish abundance and distribution increases with increased flow and decreases with decreased flow. If we decrease connections, that increases the likelihood of extirpation. Some of the effects might favor non-native species.
- BG: We can push systems past a limit beyond which they cannot recover. This is a form of discontinuity. Finding the boundaries is important.
- WO: In geomorphic jargon, an important idea is that of a critical threshold beyond which the system cannot recover. We only have so much leeway for modification that we can impose on a system. If we are not mindful, we may not be doing any decent service to the system we want to protect.

- BF: These thresholds can be difficult to identify until we actually go past them. Without a complete model, you cannot say anything about the breakpoint or you will misidentify it. This is a concern in terms of watershed use and in terms of fishing exploitation. If you keep harvesting a fish population, it cannot replenish itself. Models have done quite poorly in predicting where that threshold is. This is a common problem for any resource use question.
- KG: There is consensus that flow modification, that is, water removal, will have an effect. This will also be in terms of what the mitigation activities are. Watershed management to increase water coming into the streams should be looked at.
- BG: I really want to second that.

### Questions from the Audience

#### **Q: Who is Gila Stakeholders Group?**

MO: The Gila Stakeholders Group has been around for a couple of years, and consists of people who are interested in the Gila River and particularly in the implementation of the AWSA. Anyone who wishes to participate in the group is welcome. It includes citizens of the four-county area, as well as staff of agencies who have some responsibility in the area.

#### **Q: How were the panelists chosen?**

MO: The Stakeholders Group appointed the planning team and they chose the panelists.

#### **Q: Worst case scenario: As we heard in the forum last week – Due to global warming we may lose our snowpack in 50 yrs. Possibly years with little if any snow. If this happens, what is the impact on the Gila species and ecology?**

BG: Predicting the future is difficult, and that applies to climate, too. We have a huge number of good scientists that are working on understanding and modeling future climate change with a lot of money for a number of years. General Circulation Models (GCMs) are used to predict the flow of air and water vapor that is driven by the sun and boundary conditions. They are getting better. However, at the scale of the Gila Watershed, the results of the GCMs must be “downscaled” as it is smaller than the scale at which the GCMs currently calculate things. Until this issue is resolved, what I would say is that it could go down or it could go up.

WO: In recent years several circular models have been done. There is certainly some sense of agreement for areas like south New Mexico and Arizona. This might be a place prone to more extreme weather, e.g. more extreme monsoon and drought.

RR: I think we would be naïve if we were to move forward with flow modification and ignore the climate issue. It has to be part of the equation. There can be things that could be implemented that can minimize climate effects. It needs to be considered, but may not affect how to develop the system.

BG: The last science forum brought in David Meko, a dendrochronologist from the tree ring laboratory at the University of Arizona specializing in paleohydrograph reconstruction. David provided a long-term perspective on river flow and variability in the southwestern United States. Some of David’s work was done in the Gila, and it showed long periods of drought. We are in a wet period. Not only do we have the uncertainty of climate change, but what we have been living with it in the surface water for thousands of years.

#### **Q: Can you talk about mitigation of potential impacts of flow modification that were successful in other situations?**

RR: It is always difficult to find examples with success. It goes back to the monitoring. Many times, we have good ideas, but they do not necessarily work. Landscape level vegetation modifications have been implemented in other regions, but not to offset water development. Most of the actions we may take here may not necessarily be actions that have been applied to other systems. The San Juan River has had some reinstatement of natural flows. It is not known whether the native fish community would have maintained under no flow change. Geomorphologically, we still have some problems. Some of these mitigation measures have worked. In the Green River, temperature modification created some upward movement with Colorado pikeminnow spawning. The mitigation was the release of warmer waters, which allowed them to spawn in warmer waters. These examples might have more or less to do with the Gila.

Two aspects are occurring relative to water use in heavily wooded communities. Woody plant species, particularly evergreen, intercept precipitation at a high rate. With small rain events, most water never reaches the ground. Snow is also intercepted. With conifer stands, the amount of water in the snowpack is reduced by 20-30%. This presents opportunities that could increase water flow. In Utah, using a very rough back-of-the-envelope calculation, there might be upwards of 1 million acre-feet of water being lost in a wet year, due to the change of aspen cover to conifer. If these species like juniper were removed, it could result in less water being used in transpiration, so it could go into streams. This might increase the amount of water yield coming into streams.

WO: I think we have a tendency to think in terms of restoration, which is a bad idea. Going back to ground zero cannot happen. Alternatively, going back to try to correct is a goal of effective mitigation. Rehabilitation is more in our vocabulary than mitigation is.

**Q: Aside from the obvious positive effects of flow modifications (withdrawals) to humans, are there any positive effects to other resources, or are they all negative?**

RR: One of the things we looked at is how flow modification will affect systems. When changes occur, it does open up doors of opportunity to do certain kinds of measures that would not be possible without change. For example, in Hawaii, when they proposed changes in water use from irrigation of sugar cane to other uses, they were required to look at effects of water withdrawal. There was some opportunity for ecological improvement with this development. There can be opportunities to do some corrections to the ecosystem.

BF: It is important to understand that it is hard to see how the fish would benefit from water withdrawal. We learned something yesterday about water after it has been used for irrigation. Some of it infiltrates back into the system, maybe underground, and it can support other habitat, such as cottonwoods, in linear strips that are separate from the mainstem. That water can support trees in places where they would not otherwise be supported. Water moving back into the river after it has been diverted can be beneficial. You can see positive effects for some species and negative effects for others.

PM: But if you are using water in a different way, then you are not removing it, but just moving it.

BG: It is interesting that you can move the water and enhance the environment for Southwestern willow flycatcher.

KG: (slide reference) This model (shown earlier) shows how flow reduction affects extirpation of species. Reduced flow increases probability of extirpation.

PM: When you talk about effects, positive or negative, beneficial or liability, whose value system are you using? It depends on the individual looking at the question. Some part of the system may benefit while others will lose out. These questions may not have good answers, that any reduction in flow is detrimental.

**QUESTION #2: WHAT TOOLS AND METHODS ARE AVAILABLE TO ASSESS THE BIOLOGICAL, HYDROLOGICAL, AND GEOMORPHOLOGICAL RESPONSES OF A RIVER TO HUMAN-INDUCED FLOW MODIFICATION? WHAT ARE THE ADVANTAGES AND DISADVANTAGES, RISKS AND UNCERTAINTIES ASSOCIATED WITH EACH TOOL AND METHOD?**

WO: If one wants to discuss what the tools and methods might be, two days might be better than two minutes. There is a wide range of possibilities. In the context of trying to be brief, I would say the most basic tool available should include or be applicable to different types of rehabilitation (mitigation), and appropriate to different rehabilitation scales. We need to be aware of the wide variety of scales. It should be focused on processes that underpin hydrological processes. If you are going to alter the hydrology, especially stream flow, then by definition, it will have an effect on the food network. It might be advantageous or detrimental according to the species. The food network will be compromised or changed. One of the tools should lead to an understanding of current conditions and assessing ecosystem decline.

One needs to characterize the watershed, identify key issues and questions, and evaluate ecological conditions. Once again, if we do discern there is system decline, we have to identify the causes. Beyond that, we have another Pandora's Box and we could discuss this for quite some time.

BF: A challenge with this question is that we want to explore scenarios. Models are classical frameworks within which we ask these questions. "Models" is a broad term. It struck me that there is a big gap between the models that are typically used for "what if" scenarios that focus on land and those that focus on changes in flow and land characteristics. In other areas, there is much more process-based information going into the model. A concern is how this discrepancy, between what is used and what might be better, puts people in a position to make decisions. It seems to matter that standard operation models have different data demands and different assumptions and they operate on different scales. The modeling one does for one temporal scale can be totally uninformative on another scale. That kind of model is focused, specific, and divorced from physical habitat simulation models.

The concern is, as expressed in a paper by Kurt Anderson, focusing on the interplay between biological and physical processes, specifically how changes in water translate into changes in fish occupying the network. The classical assumption is that there is a linear relationship between the weighted usable area and habitat available due to flow regimes over time. This is a standard assumption, but it often does not have a lot of empirical support. The issue is parameterizing this kind of model. As you go from right to left, you can have a sudden drop-off in biomass production. A scenario with some support, a threshold dynamic, trying to determine where threshold dynamic might fall. We can use physical habitat simulation, but we have to modify it with other kinds of information that is most useful for us. Whether the relationship is linear or non-linear makes a huge difference. You can build this type of model for fish or riparian bird species.

PM: One has to decide what they are interested in looking at. We have within communities, individual species, similar animals, individuals, life functions that they go through. In biological productions, we are looking at the energetics of the systems. In addition, the methods depend on what it is you want to look at.

BG: Exactly.

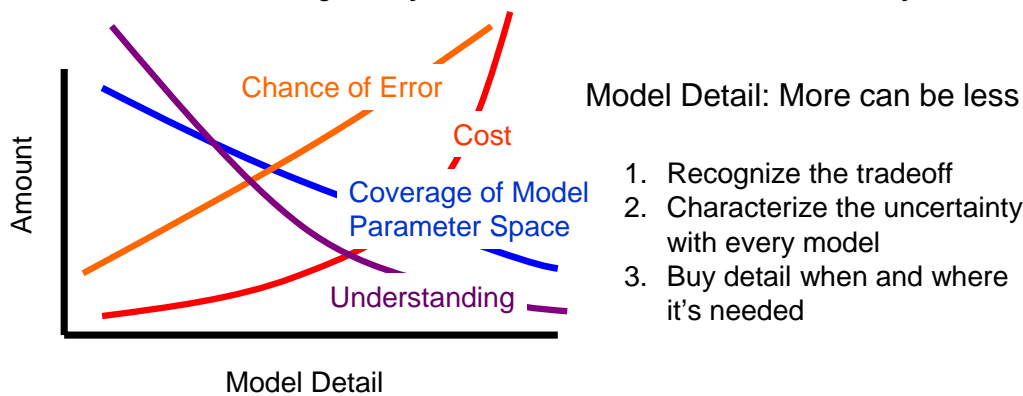
PM: For each of those there are different methods. Some are used routinely and are not very good; some are taken as matter of fact. There are standard approaches and everything in between.

BG: (slide reference, below)

## Tools and Methods Available, RJ Glass #2

### Assessment approaches for ecosystem response

- Direct and indirect **Measurements** of system state (river flow, wetted area, depth, groundwater recharge & outflow, level throughout landscape, water quality, topography, vegetative structure and composition of riparian zone and watershed, etc.)
- **Modeling (conceptual, mathematical)** of system state (variables same as above)
- **Experiments** that combine **Measurements** and **Modeling**
- Quantifying **Uncertainty**? Applies to both measurements and modeling and Experiments: Assumptions, bias, spatial and temporal coverage, etc.
- Focus on determining **Policy Choice** that is **Robust to Uncertainty**



We have talked about measurements and modeling. These are approaches as opposed to tools. Experiments are very difficult to run in real ecosystems but we run them all the time by making flow modifications. We just need to monitor and look at what happened every time we did something. We might be able to discover something that will allow us to understand process. Putting in a measurement network for groundwater, you make an assumption. You have bias because you put in wells where you can. You have spatial and temporal coverage issues. The measurements often disturb the system. One of the concerns we have is validation of specific models. When you are thinking of modifying a system, these are really policy choices. You want to be able to focus measurements or modeling in such a way that you can choose between policy choices. You want to choose the one that is most robust. That is different from the way we think of validating models in a scientific way. For example, there is a flame and we want to put together a model of combustion that represents the details of that. However, that detailed model is likely not needed for choosing whether I throw water on it or something else, or to describe the consequences of the various courses of action.

The graph is just an example for modeling, with model details on the x-axis and amount on the y-axis. It costs a lot for more model detail. As you get more detail, you get a lot more chance of error, you have a lot more parameters. When you have a more detailed model, the coverage of model parameter space goes down. You just cannot do it. You do not have a big enough computer or enough time. Then understanding goes down, so we are limited. Model detail: more can be less sometimes. We need to recognize the trade-off. Characterizing uncertainty of models is important. Use that to drive the building of your model. That way, you buy model detail only where it is needed. You move from left to right and then move back a bit and that is where you end up.

WO: I would like to have recognition of another example of a conceptual model. One that is based on empiricism, on validated field observations by Jack Stanford and his colleagues in Montana, may be applicable to the Gila River. We saw the Mogollan Rim with the headwater streams coming down, they

coalesced, the headwater transition. That led to the bottomland, a valley where there is potential for flow modification, which we saw at Cliff. This is representative of the montane floodplain; it goes through several gorges and comes through a broad alluvial valley. A typical floodplain situation. Huge variations. Look at the lower diagram, which is representative of what might happen if there is a reservoir put in below the montane floodplain. It has some fairly extreme effects on how the fluvial system operates as well as the biophysical system. This is a brilliant model of what can be anticipated if we really try to look at things in a common sense manner.

RR: I think conceptual models are an effective tool that provides some predictions to see how the system will respond. It is also important to bring in experience from other systems. A way to see the relationship to data needs and understanding better how the system will respond is to bring in data from other systems. We can also bring in the results from experiments and see if we can develop conceptual models and say we think this will happen and what does this mean for resources of importance. It is a valuable collection of experience that can help guide us with planning.

BG: The Uber Model.

RR: Conceptual models can be useful in moving forward.

KG: A multiple approach is important. You can look at a meta-analysis of other studies, but if you get too detailed you cannot extrapolate across systems. A valuable approach is to develop a basic model and then field experimentation is necessary to understand how it relates to the Gila River. I am glad you mentioned experimentation. You need to understand mechanisms. The other valuable thing is that there is a good amount of long-term data, and a synthesis of long-term data is critical to understanding. There is probably a wealth of data that I do not even know about.

PM: The response of the system is independent of the results of the model before change is implemented. The ultimate assessment occurs when one can compare before and after. It is important that one is assessing the system and not the models.

KG: That is what I am getting at; you get the general model and make sure that it applies to the current system.

RR: Being able to use existing information to look at potential effects is good. For example, looking at the bird area where there had been some extensive change, before and after. There had been large increases to the biomass of fish corresponding to the rehabilitation of the area. We might be able to pseudo test what these areas might be and see if there is some evidence that gives us an inkling for this system

BG: Follow up on modeling and scale: this brings up issues of how you go about monitoring or modeling. Let us say fish population goes up in a reach of a river. You can model that with reproduction, but what if it is important that the fish like shade, and that they now have better shade in this reach of the river. So maybe they all moved from somewhere else for the shade as opposed to increasing their numbers through reproduction. So the model might seem to work, but it could be dead wrong. This is where process is important, and you need to use models that have process as part of them.

MO: Have we covered all tools and methods available including advantages and disadvantages?

PM: We deal with a significant issue in Southwest systems: variability. Determining what happens next depends on lots of things. We have trouble describing the average condition of a Southwestern stream. I do not know if it is impossible, but I do not think we have good predictive capabilities. We do what we can, but it is difficult to predict what comes next. The past is not always a good prediction of what happens in the future. We have to realize that, as a community of scientists or managers, we

are not as good at summarizing in detail how these things work from day to day and this makes talking about the future difficult.

WO: I could not agree more. To comment on tools and methods is almost a no-man's land. We know that we have a plethora of tools and in most cases if we can identify what a stress is, we can identify with some confidence what the effects will be. But the complexity of these stresses is something we can rarely fathom. One of the best examples is catastrophic stress, such as extreme drought. The results may be infestation of insects and wildfire. Let us say that we have a huge wildfire. We have a fairly good handle on what to expect from a small area, the other physical changes that would occur as a result, but trying to integrate these over a large watershed is much more difficult. Some that has been burned, some diseased. Then we are in a situation where defining cause and effect becomes extremely tenuous. Yes, we have tools and methods, but our ability to apply those is in the Dark Age.

RR: The outcomes from our measurements may or may not reflect the important elements that are driving this system. For example, in a system, a certain aspect results in higher productivity. However, we recognize the system is variable, and a higher fish population might set the fish species up for eventual population failure. It is something we are seeing in vegetation communities, not necessarily for fish. Sometimes interpretation is difficult because the system is so complex. It can confound how we can interpret some of our own nicely designed experiments.

BG: We as scientists are interested in how to measure things and the tools to do so, but our understanding of interlinkages is lacking in respect to measurements of things. We measure within our experiments or system, but we often do not know the influences from the boundaries. For example, we might be interested in the river but do not know what people are doing on the surrounding land. We should we monitor that. What do people do? What do they use? What do they put in their septic systems? Frogs are sensitive to pharmaceuticals. We forget about these inputs. We think about the natural river system, but we should also be monitoring the land use: what parcels are being used for and what they are doing on it. The U-Bar Ranch keeps good records, for example, and if they were made available that would be extremely useful.

### Questions from the Audience

**Q: We have talked a lot about models. What process is used to build/populate these models with information? Do you use just published literature? Do you consult with experts and researchers who work in the area? Do you hold facilitated meetings to work through the process of building the framework/model or models? Do consultants build this/these, or can it be a collaborative process?**

KG: We are thinking about an approach, rather than specific tools, that begins with a conceptual model and then it uses existing long-term data or experiments to determine appropriateness of the model.

RR: If we were given specifications of the type of flow modification, it would be much easier to determine what you may need. The approach may be similar. We are providing a framework so that when alternatives are coming you can better assess. You might have reservoirs, groundwater withdrawal, depletions. Those are three very different alternatives, which would require *very* different methods.

BF: When it comes to actual decisions and the variety of scenarios to consider, there will be a time when we have to switch from a conceptual model to process-based model. Those questions are at a level of detail that needs to be asked with a process-based structure to compare the different scenarios.

WO: I do not think it is a well-thought-out process model that is important. However, we need to anticipate some of the complexities that might occur during various situations. There can be an infinite

array of dominoes, starting at the upper rim, and we cannot know what dominoes will tip until much of the line has fallen. We have to be able to integrate in some way that we can come up with the best solution. With data collection, we can validate these models in a meaningful way.

RR: Something else to consider is what we want as expected outcomes. Do you want to say, we are going to do this, and what effect is it going to have? Or do you want to say, we want to maintain these resources, how do we work towards that? We want these kinds of outcomes, what can we do to develop these vs. we want to do this, we will see what happens. The second one is a shot in the dark. The first approach might get you further.

**Q: Once potential effects are identified, what are specific tools that could be used to quantify, for example, how flow decrease causes species x to decline. What is effect on larval fish assemblage? How is this measured?**

KG: That is an interesting question. You might consider a species separate, but that is naïve because species interact. If you saw a species decline, to measure an affect on assemblage would take time. There are a number of methods of experimentation, understanding of food habits or habitat use. There is a plethora of methods for doing things. The complexity of the system makes it difficult to understand those complex interactions.

BF: It is not necessarily the case that this would be a sequential effect. One species can be declining while there is an increase in other species. If you are sampling all eight, you can use multivariate techniques to evaluate the system on a whole. This gets away from the idea that things are happening sequentially.

**Q: You have mentioned a lack of understanding of the system. Given the lack of data on many parts of the system, outside of fish, what would you load into a model to even be able to use a model? (i.e., - herbivores, birds, mammals, plants)**

KG: There is a wealth of information from other river systems that might be helpful in constructing a basic model, as long as it is general information.

BG: If you do not understand anything, you cannot even start to model. You can come up with correlations between things, but without understanding these correlations and how they evolve in time, you cannot even begin to think of what data you would want to gather for your model. They are intertwined. The process of going through model building can be done for each problem. You do not pull a model off a shelf and shove things in. You look at a problem of interest and build a model that makes sense. You start building from something very simple and grow and bring more things into it only if the model gives results you do not expect. There are three levels or steps that you build towards. The first is to get the proper qualitative responses of the system of interest from the model. The second is to get the statistics generated by the model to be representative of the system being modeled. The third is to be able to predict in space and time the exact state of the system. The point is that in the last step, very few models will get there. If we can get to the second step, it would be a great achievement.

BF: The end goal may not be some master model, but some second step where you have evidence that flow regime is connected to fish habitat and you can build process models that you can look at as a system. Here, the key factor is flow regime. It will become an evaluation of what the critical issues are. Is it OK if we lose this resource if it has a beneficial affect in another area?

WO: You have both made similar statements to what I have been saying. If you have no data to go into the model there is nothing you can do. You start at square one. Let us look at what the conditions are, like the fluctuations of water and sediment. Then you can build a database to create a model. Until you do that, it is the ultimate black box because you have no idea what is in there.

RR: I do not want it to look like we do not know anything about the Gila River. There is quite a bit of information but it needs to be fine-tuned. Maybe some studies need to be defined. We are not going in as if we know nothing, we know, but it is not specific enough to address the issues that need to be addressed.

PM: The species in the watershed and in the area are quite well known. There is a lot of information on them individually.

BG: And there is a lot of information on flow rates, weather data, and other information that can be used in a variety of models. Next step is, what level of detail? How do we look across the broad spectrum on the scale that is required, spatial and temporal?

**Q: Uncertainty is a certainty. Can you use an engineering “safety factor” approach to accommodate uncertainty and avoid paralysis?**

BF: Many population dynamics models, if they seek to explain population decline, may include a stochastic model (i.e., they have a random component in terms of one year to the next). You can ask the question in terms of, what will happen at this level where we anticipate really bad things. At this level, we think good things might happen. You can put it in terms of a probabilistic framework. You want to be sure that the things you are proposing have the least likelihood of catastrophic effects, irreversible change.

RR: From the perspective of ecological assessment, ecological risk assessment is an important element to consider. What is the risk of a certain outcome? These approaches ought to be brought in. What is the probability of some catastrophic outcome given some man-made alteration? We might have high risk even if we do nothing. These assessments can be used to determine risk of different management activities.

**Q: You build a framework of what’s important, define values, you build a conceptual model. How do you determine the appropriate time to move from a conceptual model to a process-based model?**

BG: All conceptual models are process based.

WO: They are basically the same, maybe only different in terms of complexity.

MO: Someone made a distinction between conceptual and process based.

BG: You cannot move from place to place without process, otherwise a model is only applicable to the location where it was developed. You have to do things process-based.

WO: Process-based means probably the whole array, if we want to refer to a conceptual model (this is semantics). If we want to be more elaborate and look at a process model, we must consider different concepts, one that leads to another through some set of processes.

BF: A biological process model example. Someone wants to go out and evaluate temporal changes in population abundance from spatial changes in population abundance based on availability of flow. The process would be, here is a form that represents movement from x to y, or do we instead see an absence of dispersal. You build a model with a process that includes spatial linkages. That is where the biology comes in.

**Q: Do we have any modeling/data on effects on the ecology of similar rivers that flow or hydrological changes produce? What can we learn from these to help us develop our model for the Gila?**

BG: Stuart Bunn obtained certain principles by from looking at a wide variety of rivers. That is the kind of thing we are suggesting. Take information from somewhere else and abstract it to process. Example: if I take a ball and drop it here, measure how it falls, and develop a model that relates velocity, acceleration, etc., I can go to Australia and use it. That is the usefulness of a process-based model. Others have tried to do this regarding flow modifications in rivers, and a consensus has developed across the ecology community on this sort of thing. There are some direct relationships between what we see here and what we see on other rivers.

KG: This is a work in progress. This is not unique to the Gila River. There is a synthesis group that meets in California and they are looking at the same questions. I do not want you to think we totally understand this; there is a lot of information out there but a lot of ongoing work that is important.

PM: There are many books devoted to the study of just that, and journals in the physical sciences as well.

WO: That question is of intense interest to the Chinese with their reservoirs on huge rivers. The Yellow River in northern China is one of the most regulated rivers in the world. This is not a concern to just us sitting here, this is a global concern.

**Q: Can you name a Southwest river that is an example of a river that has maintained its biological integrity after human-induced modification?**

KG: The Gila River is a good example. Unfortunately, there are few others.

RR: On the Gila River, the current withdrawals were not done to maintain integrity. This is in contrast to what is going on in the San Juan and Colorado Rivers with impoundments where flow recommendations are being implemented. It behooves us to do these analyses as it could have profound effects or minimal effects.

PM: It is hard to identify a river that has shown minimal effects. Also, even in relatively unmodified streams, there is the issue of the presence of non-native fauna. We have some examples without impoundments. San Juan Creek is an example.

**Q: How do you determine what tools to use when you have diverse outcomes and diverse interests moving forward?**

RR: You have to prioritize what values of the system are important. They may be social, biological, or ecological. But without making those decisions, it is hard to move forward. If they are made up front then we can better meet those needs. Without those outcomes, I do not think you can move.

BG: That is the question that drives all the modeling. You have to define what you are interested in first. Look at the things you are interested in and whether they are going up or down with the things that you do to the system. You link those together with the appropriate science and that tells you what to go after. You are not pulling a model off the shelf; you are not bringing in every interest under the sun.

PM: In some circumstances, the Gila River is a good example. You have endangered or threatened species; that gives you a pre-indication of what is important. Gives you some prioritization. Tells you what must be studied in terms of effects. Those endangered species by default rise to the top.

**Q: What processes are used to populate models with information?**

RR: First part of the question is easy: all of the above.

BG: And more, there is a whole bunch of indirect data you can make use of. Many people use geology to predict permeabilities underground. Understanding how rocks are layered can give you permeabilities

indirectly, without measuring them. Satellites can give us lots of information that could be useful to populate models. New information can come every few days from them. This information can be used to design models. You can see vegetation cover, multi-spectral analysis. You can characterize what occurs in zones. There are ways to populate models that are not pump tests. That is one of our frustrations with this question, there is so much that could be done. There are so many tools that could be used.

WO: Especially with groundwater models, historically, the sophistication of them has been far greater than our ability to measure. All of a sudden, there is this explosion in ability to fill these models. It is this easily obtained and verifiable information that we can apply to models now in a constructive manner.

**Q: Please explain the following, with an emphasis on river diversions during flood stage: “The nature of the flow modifications determines the effects.”**

RR: We have not been speaking about specific flow modifications because we have not been provided with specific flow types. You can be using off-site storage, groundwater, they are very different in terms of flow modification to the system. There are other things that we are not talking about that affect flows. Until we get more specific about the flow modifications proposed, it is difficult to talk other than generalities.

**Q: What is the difference between what is predicted and actual impacts by these models/methods?**

WO: In terms of rehabilitation, a number of studies were designed to compare before and after. That is the essence of a rehabilitation project. Collect data on how a system is acting and put into effect remediation efforts. Then you have to identify effects on the system, both positive and negative. A project that does not provide effects on rehabilitation efforts may be useless.

BF: In the context of discussing flow modification, this gets back to the issue of evaluating after the effect, and how it agreed or disagreed with predictions. There are limitations, because at the landscape scale there are never resources for the monitoring to follow through after changes have taken place. Agencies do not allocate resources for after the change to assess long-term affects. There is a need, especially with the Gila to monitor after the change. This is part of adaptive management. If you have gaps in data, you cannot respond.

KG: There have been studies that look across relationships. In a sense those are predictions, if you hold a data point out, you can predict what could happen there. You do not necessarily have to go to a new site. They all follow the same pattern, so there can be some prediction.

PM: The question asks what are the records or experience; I agree there usually are not resources for that information. Example, Glen Canyon Dam process in the Grand Canyon has done post-management action modeling, including riparian specialists, geologists. The examination worked in terms of its predictive value, especially when they talked about changing the discharge from the dam and predicting the effects. All this was done in the context of adaptive management. Some people would say the record there is positive. You can spend a lot of money and time and still not come up with a good result.

RR: There has been a lot of work on the Colorado River, bed-mobilizing flows, what follows lower flows. There is a lot of information. We have done a good job at understanding those systems. In the Grand Canyon they can predict what are the sediment moving flows. They were quite successful. The challenging link is that we expect an immediate biological response. They often do not have one. We do the change expecting a response but we might not see one for 10 years. And then we might have to

change it again to get that response. At some level, we have to hope that if we provide it, they will come. We rarely monitor long enough to see the biological responses.

**QUESTION #3: HOW MIGHT INFORMATION OBTAINED FROM BIOLOGICAL, HYDROLOGICAL, AND GEOMORPHOLOGICAL STUDIES BE BEST ASSIMILATED AND INTEGRATED TO UNDERSTAND THE EFFECTS OF FLOW MODIFICATION ON ECOSYSTEM FUNCTION?**

WO: It seems necessary to develop an understanding of how and why changes have occurred, develop a plan that contains a clearly defined objective and technical design and has public recognition and political backing, and to outline and conduct post-project activities that will yield indicators of success (an extension of technical design). That is one of the basic objectives in the stream corridor rehabilitation projects. To further understand effects of flow modification on the Gila, the processes must be identified. I have a slide with a graphic representation.

KG: From an aquatic ecologist point of view, a hierarchical approach is necessary. What is driving these questions is fish. Then how this hydrology affects the fish seems like the logical sequence. My simple thinking of how flow modification affects the biology, you need to start with the hydrological changes, how does that change geomorphology, and how does that affect the ecology.

RR: I think we really need to assemble information to try to understand how the system functioned prior to large-scale human influence. To truly understand how it functioned, data has to be assimilated: flows, geomorphology dynamics, sediment inputs, and how groundwater works in these systems. This all has to be put together first. I think we need to define how it works today and how it is affecting the biota. We can reconstruct the physical habitat historically. Then we need to determine what people want and then move forward. We need to know where the systems been, where it is today, and where we can take it. This is the meta-analysis I talked about earlier.

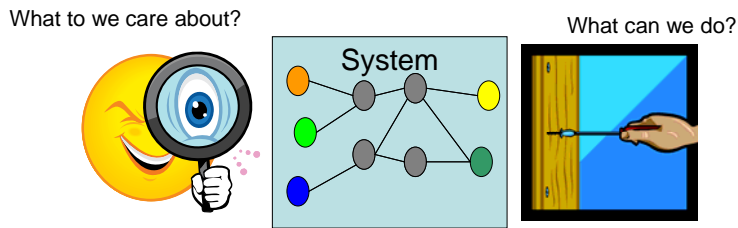
BF: About integrating information is a situation that falls to passive developing representative model systems. A framework in which this information can be put together. Given that these questions will be asked in terms of alternate water withdrawals, they have a specific spatial character to them. There is a need for this assimilation to take place within a spatially specific model. Geographic information systems based with satellite information available. These can have a hydrological component, transport of substrate material, and biological components. This feeds back into a hierarchical approach. A spatially explicit structure allows you to bring that information together to work from small to large scales and put the pieces together. It is a framework that has been adopted in other systems to come up with questions of dynamic linkages. Many long-term ecological sites have developed these hierarchical approaches to take in information. Many things can be learned from the best practices of people who are building these types of models.

BG: The bottom line, hierarchical models look at dependencies between scales and different models, types, parts of a system. It is thought of as a system of systems. There is no general-purpose model for the task at hand. We have many pieces, but not put together. You might not even want to put them together. It may be too much.

There is no general purpose model for the task at hand for handling the agricultural ecosystem, I think this is more socio-agro-ecosystem. You want to develop this model for a purpose; very specifically, there would be a set of purposes. Interdependency modeling forces integration across specific domains to be precise, e.g., how fish are influenced by vegetation, by water. It looks like a network of interdependencies. The model application allows you to determine the most important link. You can also turn it into a computational model. So you take a system and you focus on what you care about, those are the little circles (on the left hand side of the system on the slide), and then see what you can do like modifications, rehabilitations or mitigation, things like that (the circles on the right hand side).

### Assimilation and Integration to yield Understanding, RJ Glass #3 Systems Modeling focused on Interdependencies

- There is no general-purpose model for the task at hand: Managing an “agro-ecosystem” under human pressure with always unforeseen and unintended consequences of human action.
- A model describes a system for a purpose
- Interdependency modeling forces assimilation and integration to be concise
- Model application allows identification of critical areas where funds should be focused



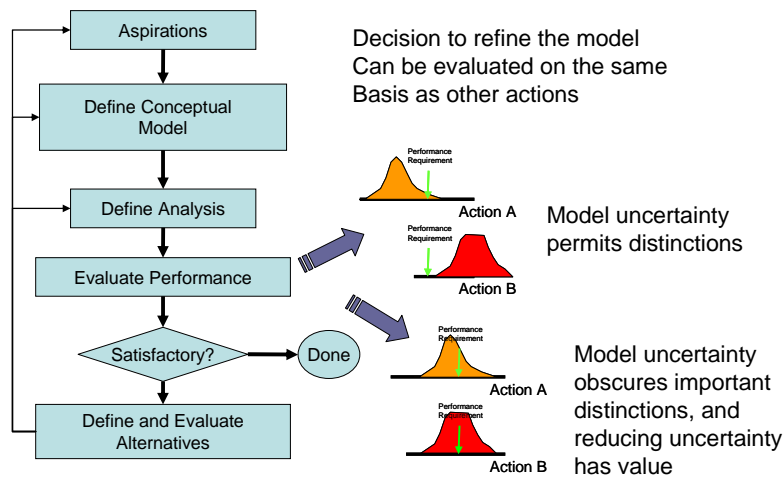
#### Interdependency Model

Additional structure and details added as needed

Then you put the interdependency model in place that connects what you care about with what you can do, but what you see, they influence each other, and there might be arrows, one direction, not bi-directional. Then it is based on what is needed. You put in there what you need. Then next slide shows a process or systems framework, you start with an aspiration, define analyses, then evaluate performance and if that is satisfactory, you are done. If not, you evaluate alternatives. If action A gives you yellow region and action B gives you red, there is a clear distinction; but when they are overlapping, uncertainty needs to be resolved. You may need more data, more specifics. Across all the things we do with systems analysis, model conceptualizations have to do with the things you want to do and the things you care about, and then people go through this process.

### Most Pressing Tasks, RJ Glass #4

#### Develop Systems Interdependency model and incorporate uncertainty as an iterative process



RR: None of this kind of synthesis, bringing information together, will happen without a team of people to implement and integrate it. There has to be someone there to make sure the pieces are brought together, it has to have a facilitating group, people to implement it. If all of a sudden five contracts go out, and no one ever brings it back together, it will not meet the needs that some of these approaches bring. That team can determine what should be the elements that we are concerned about, and help direct the effort to work towards those needs in order to effectively implement those tools. This should not be a job where you get a contract to do this job and that's it.

PM: I agree, understanding effects of flow modification on ecosystem function is a concept/construct beyond my basic understanding. There is a level of complexity that is beyond our mathematical capabilities. People who like to draw little boxes and put down names can spend entire lifetimes doing this with one ecosystem. It is important to determine what components of ecosystem function are really important, and you need to know in order to examine effects of flow modification. Then you put resources into learning and knowing those components, rather than trying to understand the entire ecosystem function, which I believe is beyond our knowledge.

### Questions from the Audience

**Q: How much diversion of the Gila River goes on today in New Mexico for agricultural and other uses? How does current diversion compare to historical such diversions?**

Craig Roepke (Interstate Stream Commission staff): Including pumping and supplemental pumping, an annual average of 27 KAF per year is depleted throughout the entire Gila River basin. The limit is 30 KAF per year. For the Gila River alone in New Mexico, probably about 18 KAF per year with some returning through return flow.

BG: Can you tell us how much comes out of it, 140 KAF flows to Arizona every year, 114 KAF arrives from the wilderness area. So, about a 25 KAF increase from the wilderness area to the border with Arizona.

PM: That makes sense because of the larger watershed.

**Q: If we assume we know how to integrate biology, hydrology, and geomorphology, how do you assimilate socioeconomic and public interest information?**

BF: There is a whole group of researchers who use the idea of tradeoffs to address this. You have socioeconomic concerns on the one hand, and biological concerns on the other hand. Those are not just apples and oranges; they are really, really different. Dealing with different currencies requires you to deal with a framework that allows for comparison across the different measures. If you give up this much, what do you get in exchange on the other side? That is called building a convex curve, a particular set of solutions that shows the best outcome for any given value of x. One endpoint says to hell with the species, take water out to maximize socioeconomic values; the other side says take no water out. Between these different extremes exist different scenarios. People use this modeling approach when asking, for example, where to build fire stations to optimize usage. Some people will be farther away, some people might be bothered by being too close. Scenarios represent different weightings. Science stops at identifying solutions and people have to choose and act.

WO: A more specific example of this is the same thing applied to stream flow and hydrology in general, and more specifically it is the way in which water is used. In a sociopolitical sense, water is viewed as a commodity with a dollars and cents value. The alternative viewpoint is to see water as a service, with an intrinsic value and no dollar sign. The tradeoff to accommodate economic desires for that water, however much of it is appropriated for that use, is that the ecosystem will suffer. If we assume that precipitation through time will not change dramatically, then there are a few options. One of them is

the amount of water left for biology factors to sustain themselves. For each cubic meter of water that is taken, that is one less that is left for fish habitat or growing cottonwood trees. An evaluation has to be made on how we want to do things. We as scientists can only provide opinions.

BG: These are exactly the things you do in order to frame the problem. A number of folks have worked with social scientists and taken steps to put in different policies and see what happens. At the last science forum, John Bolte, a biological and ecological engineer at Oregon State University, presented the process used to successfully assess alternative futures in the Willamette River basin using stakeholder input, geographic information systems (GIS), and a simulated community called Evoland. In the Willamette Valley in Oregon they started by modeling. They did the entire valley, and they looked at three things: policy as it was, policy that was greener than current, and policy that was more personal-rights oriented. They preconditioned their simulated community by their voting records, and generated alternative futures with the three policy orientations. The work brings in many of the intuitively human aspects of the problem.

**Q: Relative to BG's slide on interdependency model, what other aspirations at this point have been identified?**

Topper Thorpe (co-chairman of the Implementation and Technical Committees): They have been partially identified, and they are really diverse.

RR: If they are partially identified and highly diverse, then there needs to be a team to bring those together, otherwise nothing will happen. Or certain issues will drive it because they have clout, and other entities will lose out in that process. I think it behooves them to come together

BG: And keep the diversity.

BF: That is OK, it does not have to be a single solution, whether agent based or tradeoff based models. You can identify possible solutions if you keep that diversity. You do not have to have a single monolithic answer and you do not have to sing kumbaya.

BG: Getting back to Evoland (Willamette, John Bolte's work), the kind of things measured were species diversity, consensus output in a variety of categories, certainly logging, water resource issues, fish were in there. So it was very diverse. You can define these things by interests, the things you want in your model. You want to know whether they go up or down with a given policy implemented, you can use them as system measures, what is "best" will be different for different groups in the watershed.

BF: But they do act as guides for the modeling, they act as boundaries for trying to put together an integrative framework, knowing the constraints and possibilities. It is absolutely essential to developing a framework.

RR: One entity puts forth an idea and they research what the effects will be. This is the usual approach. In the past, the approach has been, we are going to develop water, what are its effects? This (the other way) is a more open approach. It opens doors for opportunities.

MO: The process you are talking about is compatible with NEPA.

RR: You have already done many of the evaluations. Critical resources have already been defined by the communication, and you hope most people are on board with the alternatives.

**Q: When is it appropriate to determine the type of diversion? Can you do an effects analysis before that?**

PM: No. You can pay someone.

BG: Can you do parts of it?

PM: Absolutely you can parse it out, and get a large sweep of potential outcomes, and it is not useful for making decisions.

BG: And then the cost goes up.

WO: If we can have a specific scenario of what the withdrawals would be, then models could be constructed. The indirect approach is to come up with an assumed situation, but it is more productive for the modeler to have some idea of what he or she is working with.

KG: In order to assess impact, baseline conditions must be established. These are lacking in most studies because of an inadequate baseline and the time necessary to collect that data. Climate variability is difficult to predict. Ocean fisheries have collapsed. There are many cases where you cannot collect baseline data. If you can evaluate the response of the system, this allows you to adjust your future modifications.

PM: Timing is important too. A baseline today does not go very far into the future.

BG: I am thinking aloud here...if you have an appropriate model and a very large computer and you could run it to look at a large number of locations and diversions or modifications, you could go through that whole sweep, you could do the problem with fewer constraints. And maybe then rank possible scenarios in terms of detrimental or positive effects. You could compile all that information. We did something similar looking at pandemic influence strategies, and you were able to distinguish between different methods and rank them. You might be able to do that within this context, but the model does not exist at this point. Maybe we could do something like that in the future.

KG: I think the challenge is data limitation, in order to make that projection. Having enough data to construct that model would be a challenge.

BG: How quickly can you become process rich? You could vary parameters and scenarios quite widely. We are getting to the point where we can use computers that way. In only a week, you have done millions of scenarios for input data you wish you had. You use: it cannot be less than this or more than that, maximum entropy theory...there are ways to handle some of these things, but it is not trivial.

WO: Decision support systems, which represent computer models, are what we are talking about. Represent a start or approach to addressing the problem we are talking about.

**Q: If you were given a concrete flow modification scenario tomorrow, how long would it take to develop a high confidence effects model for the yellow-billed cuckoo or spikedace?**

WO: A prediction might only be a potential of global climate change occurring, I think a person would be pretty foolish to say, "I have confidence."

BG: Confidence in a prediction might be difficult, but confidence in a choice is different. Focus on determining policy choice, rather than predictive capability.

BF: The information that can be provided with confidence, is that this approach is better than that approach. More like ranking, this choice is better than that.

MO: This question is asking how long it would take.

BF: For one species on that scale with available geographic information systems data and you can coax the data from people with it in their files, you could have one post-doc student and one graduate student work on it for a year and have your answer.

**Q: Isn't the whole process of developing a model inappropriate unless there are plans to test and validate the model prior to undertaking the action (withdrawal)?**

RR: You cannot validate the model in the system you are applying it to. You can validate portions of the models. How its predictive behaviors have been observed or not, if they are close to parameter sets in your model. There is no way to validate so that you get 100% certainty.

KG: One of the steps in the whole process is to test the steps in the model. If that is a key assumption, then pieces of the model can be tested.

PM: Bill is talking about developing the model specific to the situation. Taking a specific model, crunching the number and coming up with an answer. The currently available models are not validated, not tested, quite simplistic, and include only a few specific aspects of the system. It assumes that this simple set of parameters is what is important to some specific species. Although we have good habitat for spikedace, for example. I do not know if these models have been validated for Southwest fishes. If the data are published and software is there, it could be done over a short period of time. But developing a model would take financial and academic resources that Bill suggested.

WO: Taking the devil's advocate example, we may not have that sort of control. If we look at lab experiments, we can say with confidence what the effect will be. We do not know what the effect will be of dewatering. There are numerous variables that we cannot know very well.

BG: The Consumptive Use and Forbearance Agreement (CUFA) says that New Mexico can take up to 14 KAF per year at very high flow rates. So do we need a model? If you can take water at those times, not worrying about what we do with it, say it just disappears. What kind of model do we need to know whether it will affect this bird, spikedace, loachminnow? Your goals are set and you can try to set up the question and problem so that it is straightforward. It can cut through the mustard.

**Q: The session has focused on flow modification effects on aquatic species. What about the effects on aquatic species if the Gila remains a largely free-flowing stream?**

KG: All we have are existing data that show it is relatively stable in the Gila-Cliff Valley; the upper Gila has shown fluctuation. Climatic change, consecutive droughts. Even without flow modification, the system can still be compromised.

RR: There are potential changes with inputs to the system, or climate change issues, less snowmelt runoff, effects to aquifers being recharged. Some of those changes are things we set up. The second element, what are the options under today's water users in the systems, what if tomorrow they manage it differently, it could completely change the water in these systems. We could have sections dewatered. It can be altered just by the way it is currently used. Because the system can change, it would be problematic to have the attitude of; if we do not do anything, the system will be fine. It may be in peril. An example is the bird communities in the Midwest. There were a lot of songbirds. As more corporations bought land, they took out fence posts, plowing for row crops. Some of these bird populations crashed. We have to be cognizant about these things. We have the opportunity to regulate by setting better bounds. Not having identified those values lets things slip through the cracks if the situation changes.

PM: There are many engines of change; we have not talked about fire or urbanization. Species will naturally and historically be extirpated and repopulate elsewhere. Those would not come back without human intervention. Doing nothing is not realistic because things happen in the corridor and watershed. Whether we like it or not it will change.

BG: Just think, we could increase flow in the river by putting a large housing community in the area. Water would move off the roofs and driveways and right into the river. That is a land use issue and that's not being talked about. And now you have plenty of water to use somewhere else.

**Q: Can you use sensitivity analysis to bracket potential outcomes of diversion?**

BF: Yes, but there are other tools. Sensitivity analysis only involves one parameter at a time. Other kinds of analyses include scenario modeling or examining the correlations among parameters; they do not actually manipulate each parameter, and instead look at a range of possible scenarios, building the scenarios up.

BG: A final way to look at this is model uncertainty, uncertainty in the fundamental physics within a model. You run advection and diffusion simulations if you do not know if one or the other is most important in your system.

BF: If you build a model and it has a parameter, flow rate, if you change that parameter it will change the outcome of the model. You figure out your best estimate and you change it by 10, 20% up or down and then you ask how does that influence the outcome? If you take the 10% change and see a 500% change in the outcome, it is a sensitive parameter, in isolation. Issues about correlation, scenarios, and model uncertainty are not addressed with sensitivity analysis. If you get into comprehensive modeling, you definitely initiate a variety of examinations.

BG: Almost always, a good scientist will put in parameters with uncertainty, and do a sensitivity analysis as part of final project. Just as you give a number plus or minus something. The model is no different from another measurement. If you do not see that in the output of your reports, you should ask them for it.

RR: If a parameter is not very sensitive, an estimate is OK. If it is very sensitive, you may have to spend a lot of money to get a better estimate. It can lead to instabilities in your model (sensitivity analysis). In one model I developed, I tweaked a parameter and got totally different results. It led me to a change in the model. It can identify weaknesses in the model, and identify relationships that are inappropriate.

BG: This is depicted in a slide I put up earlier. Where they overlap, you can go in and find distribution to get better measurements. I may redefine my conceptual model or I may have to go back and change my aspirations.

**Q: You use the term “ecosystem” yet not once have the panelists talked of the aquifer, groundwater, or inflow except fleetingly – why?**

BG: I am a hydrologist. It is in there.

PM: It is the critters, the plants . . .

BG: . . . and the people!

PM: Of course, they are the driving force in many ways.

WO: In terms of looking at things, I think that the upper Gila River system is a good example in that it is easy to identify three hydrologic components. One most obvious is streamflow or surface water movement. A second is groundwater within the alluvial aquifer, meaning a saturated condition beneath bottomland features. The last one is more problematic, a resource in bedrock, artesian, and probably more difficult to quantify. As for alluvial groundwater and surface water, they should be combined. They tend to be interactive.

BG: If you push this out a little further, if you add humans, and people pump wells, groundwater, then you should be thinking about flow modifications that are to come. There is a time lag, so it could just be we have not seen them yet, if they are pumping out of aquifers connected to the Gila River. There have been many laws and litigation surrounding this connection elsewhere. So that is important.

**Q: At the 2006 Gila Science Forum, all but one of the six scientists participating agreed that there is great scientific value in leaving some rivers undammed and unsiphoned so that there is**

**a model to study in river restoration. (The sixth scientist recused himself.) How should that value be weighted in the decisions about flow modification?**

RR: That is not the scientists' job to decide. It is up to the citizens, politicians, and policy makers.

PM: It is a challenge to find the systems to compare with and that can lead to a global search for streams that are unperturbed. There is a search for nature that is untouched. Humans are the overarching determinant of what happens.

**QUESTION #4: RECOGNIZING THAT TIME AND RESOURCES ARE LIMITED (TO ABOUT ONE YEAR AND \$1 MILLION), WHAT ARE THE MOST PRESSING TASKS (INCLUDING, POTENTIALLY, FILLING INFORMATION GAPS) THAT WE NEED TO ADDRESS IN ORDER TO ASSESS THE EFFECTS OF MODIFIED FLOWS ON AQUATIC RESOURCES OF GILA RIVER?**

KG: One million dollars is good but a year is difficult. The baseline conditions are obviously a challenge and anything in the field and on the ground takes time. And so we are sort of left with, it is potentially impossible to reasonably evaluate potential effects of flow modification in that timescale. You are left with a conceptual flow model, gathering data from other systems and that is what you can do in a year. I just want to comment on this specific question that is a huge constraint.

RR: I think that time constraint goes beyond biological and ecological and looking at variables to the review process. There needs to be input from different entities, members of the general public, or other stakeholders, their input needs to be reviewed. Even if it were done in a year, that product needs to go through a review to make sure it addresses concerns of other constituents. The timeline is an issue.

PM: I would think the first question is to define and describe the project so that whoever does the assessment knows what they are assessing. A one-year biological study is not a worthwhile endeavor. There are abundant data on the two fish and the bird. One could assemble those data with a known project and speculate an effect, but that leaves no confidence. No matter what approach you take, the confidence will not be high. That is something not well known before a project is complete and often not afterwards. The most beneficial approach is to do something similar as today. Bring together a group from a variety of disciplines who can integrate a variety of effects. Confidence will not likely be high, but you would at least have some credibility. There is a lot of case history out there about how to examine flow effects; e.g., the Glen Canyon Dam Adaptive Management Program over the last three decades. If nothing else, it shows how an extraordinary expense of time and money might not give results as productive or predictive as we might like. If someone actually has \$1 million and a year, they would certainly get an assessment on the two fish and the bird and then move forward.

BF: A fair portion of the time would be spent compiling the information. There are several years of information available from a biological standpoint. Turning to satellite data, there is a considerable amount that would give us a large-scale perspective on changes. Those kinds of resources exist, but in order to use them towards a specific project, they need to be brought together and linked together. I think the time well spent would be focused on data compilation rather than data collection. New data could be advantageous on the issue of how spatially connected different populations are. There is a need to discriminate between changes in population locally as opposed to spatially. Some kind of information, maybe from other systems or related species, in a surrogate fashion. I think this is a key question. For example, a translocation experiment of a bird to see how translocation affects spatial distribution, to see how functionally connected different parts of landscapes are.

PM: Let me reemphasize the amount of data available on the two fish and bird. They have been on the endangered list for a few decades. They are very well studied; a lot of money has gone into studying

them. There is substantial data. If someone has an idea to do something in the next 12 months, we need to be more creative in assessing flow effects.

WO: A year is certainly likely to be inadequate to make a reasonable meaningful assessment. I continue to feel the necessity of having studies based on the focus that when one makes a change or stress on a system, that change or stress will have ripple effects throughout the entire drainage system. When we forget that, the interactions of processes, then we are not understanding fully. We need to anticipate future change and future modifications to the system and climate that comes into it. I wanted to show a diagram, not a specific site, just a reach of stream, the upper Gila River is no exception. This diagram is for a valley in Virginia. The point is that if we affect change, whether increased or decreased flow or change in transport of sediment, there will be changes in channel bed. There may be channel narrowing or widening. Even more important, look at representation of various bottomland surfaces, floodplain, and depositional bars. I want to point out if we make modifications so a floodplain is no longer a floodplain but becomes a terrace, the riparian zone vegetation will change accordingly. A good example is in the Shenandoah Valley. One of the species, Black Walnut, never grows anywhere else except floodplain, resistance to floods. Similarly, sassafras will only grow higher. So if we change the hydrologic machine, we change the vegetation by definition. By implication, we change aquatic biota, too. This is one component we have to internalize before we make changes. You do not want to be caught off guard as to ramifications.

BG: Yes, one year is not a lot of time. It precludes many things most of the panelists have mentioned. I am just going to tell you what I would do. I would go here (to slide) and define my aspirations ASAP. I would push through the process on this slide within a year; get together a group of people, including system engineers who are used to looking at lots of systems. They would analyze the system from scratch making use of experts and all available data, and they would make it up (based on estimates) when they did not have it. You get the experts to agree. You put together a simple transparent model that can address your aspirations. The kinds of things you have to get information for are things like satellite imagery, or geomorphology work such as in the report by Mussetter Engineering, or the work of Ellen Soles in Flagstaff (her work is landscape oriented). That has a lot of value. Why do biological studies? You have data on those things. Some of how we see change in time, how land use has changed, can be integrated into the best first-cut interdependence model you can make. This team would move through the course of the year and evolve, it is difficult to define, you have to get good people and build trust. But you could do it. I have been involved in things like this, knowing nothing about a system, and we pushed the process through and ended up defining policy in less than a year. But you have to define your aspirations and they have to be clear and get good people who can think outside their boxes and interact well with others.

An aspiration is a goal, or something you would like to accomplish. Something we would like to have done, but we do not even know if we could do it. An aspiration is something you are attempting to do. An aspiration might be to define whether or not the CUFA flows if they were taken would influence the system you are working on. If you can clearly define it in a way that is something that can be asked and answered, then you have a chance of moving forward and coming up with a designed solution. This is an engineering approach for complex systems that is used from global energy supply and demand to things like this.

MO: I think the group has been using aspiration to express the values of various stakeholders.

BG: That can be. You may have to come up with a ranking of values.

MO: Or integrate values.

BG: Exactly, I am not just a scientist. There is the side of me that wants to accomplish something. Let us define a problem in a way that can be met with a solution that even in the face of uncertainty, allows us to make a decision. And then you monitor, because it is going to change. And then you have to make something flexible enough that you can change it. That is a general approach humans have been using for centuries. But I am suggesting a methodology that makes it more transparent, goes beyond the way we currently think. Models show you what your answer is and how you got there. That is what I would do; I would turn to that approach.

KG: That approach of bringing together a group of smart people will lead to identifying these information gaps. We cannot tell you what those are. That assembly could integrate it and define those gaps.

RR: I agree the year should be used to conduct synthesis with existing data. It would set the stage to evaluate alternatives. Then we can define aspirations. Use the year to bring together existing data and define what kinds of outcomes are important, and build that into the framework. The money would be best spent figuring out what can we get out of the existing data. One should also evaluate economics, land use and industry changes; for example, when is it likely for there to be housing developments? This can help figure out effects that could occur. Synthesis of existing data should be the first priority.

BF: I think in the process of data synthesis and compilation it will become clear that there are significant data gaps, because the data available were not collected for the purpose of a synthetic effort. So there will be a mismatch. Gaps will emerge as the compilation goes forward. You can guess what they will be, and borrow strength from other sources. But in some cases, there are systemic problems in regional scale models. Not enough good information on the space/time dynamic, or on the human side, how people are moving within the landscape and priorities. That can be a weak point. You can take a best guess, but often later you will wish you had known this.

BG: You make up a model, and do the uncertainty/sensitivity analysis and it shows you if that is important, and if it is not, you do not go down that hole.

BF: Realistically those data gaps will emerge from data synthesis.

BG: Like the geomorphology report by Mussetter Engineering, one of the critical things with high flows, the amount taken out by the CUFA would not influence overbank. That is a critical conclusion that could be revisited. Identify those things that are really supportive of making a decision. Go back and make sure those are good.

### Questions from the Audience

#### **Q: What is the impact of taking out at high flows?**

BG: See the report by Mussetter Engineering dated June 23, 2006, and the section on inundation and frequency. Their conclusions were that it basically did nothing to the hydromorphology by taking out water at high flow rates.

RR: I am not sure we would agree that we do not know what data gaps are. We are not in a vacuum, but the most important way to prioritize the gaps is through data synthesis. If you find a parameter that is important, or there are critical elements. So yes, we could list things, but is it important? We would have to wait for the synthesis to prioritize them.

MO: Not just the synthesis, but also knowing stakeholder values?

(General agreement among panelists.)

PM: Comment about stakeholder values. Different stakeholders have different values. Assessment of environmental effects at this level might be less relevant. The values might be conflicting, and it may not be possible.

BG: You could come up with an integral measure of “happiness,” with stakeholder values variably weighed and combined into a happiness index. We could then make everyone value everything equally and see what scenario would yield the greatest happiness.

PM: I do not think that would be the way of assessing the impacts of the stream in the groundwater.

BG: A value turns into happiness, social value. That is the trade-off analysis; there is no single solution, but rather a collection of solutions that will yield happiness in varying degrees. Biological happiness is contrasted with measures of happiness focusing on water extraction, and the benefits for stakeholders using the water for agricultural uses.

KG: The native species is not a flexible variable.

BG: Some of those things are constraints, so if there are laws that cannot be changed, then they become constraints.

PM: The effect on fish, for example, is independent of the effect of the socioeconomic end of things.

BF: I was on a project examining resource use on the Willamette. People were interested in dam removal to increase effectiveness of salmon runs. But removing dams has a cost. They were hydropower and water storage dams. So the question was, how does one frame the problem when you have very different measures? We tackled that with a trade-off analysis; as you remove more dams, how does that reconnect, and what are the costs? These measured against each other.

You could have river connectivity on x-axis and loss of hydropower on y-axis. If we do nothing we are at (0,0). If we are up at (100,0) we reconnected whole system, but lost all hydropower. We hope to get a reverse shaped L curve. The more you remove dams, you make the river people happy, and little to no hydropower removed, they are happy too. But if you have the curve going the other way, it is a different scenario, wherein there really are no good solutions that improve connectivity, but it does not cost hydropower. This kind of analysis can be applied in the Gila, but with many more axes. It allows you to talk about biological and socioeconomic concerns. There is some interconversion possible within this framework.

BG: Another area this is done is in health. There are costs associated with procedures. Quality adjusted life years are gained by doing something. You do not want to give up a person's years of life. You try to find scenarios where it costs less but you get more in terms of life years. The folks that do this are health economists. These are the kind of scenarios you want to find.

**Q: How do you build into the process the ability to reverse course if outcomes are not what was originally desired?**

RR: Adaptive management is necessary. Management may need to be changed. How that can be institutionalized into a program is challenging. If a lot of money is put into a structure to develop water, and there is a detrimental effect, it is very expensive to remove a structure such as a dam. It is a real challenge, but it needs to be done if there is a way to mitigate these issues. The other way is to look at mitigation. We do not have to necessarily stop the project, but we can look at mitigation in a different way. Adaptive management is an important component. However, problems with adaptive management can arise if you do not have an escape valve, even if you are fairly certain of the outcome. If that outcome is different and there's no path back, that is high risk and maybe not desirable

WO: This is a wonderful question and has been applied to many different scenarios. One really noteworthy example of ramification is from 1965 and an extraordinary flood of the South Platte River. It wiped out all but one of the bridges in Denver and caused millions of dollars in damage. There was an immediate outcry for reform. Because of the emotionalism of the situation, there was not good science or engineering. A dam was constructed 2 times larger than was necessary. It was built on the assumption that the river could flood the same way as the tributary. For the situation right now, let us make sure it is founded in good solid investigations as opposed to emotional responses.

BG: Here is a hypothetical example. The y-axis is fish population and the x-axis is flow modification. Let us assume with flow modification, flow rates go down. Take Keith's data that with an increase in modification, the fish population decreases. With modeling like econometrics, you just extrapolate. My bet is that you go to some point and get to a threshold and then the line drops off (to 0 on the y axis, fish population). And if you do what you are doing incrementally, and you start going down and you stop and think you can reverse, but you cannot follow the same path back up, it will be something more like a line that dips below the original line. It is hysteretic (history dependent). It does not move back along the same line. And if you hit 0 on the y axis, you cannot recover unless you bring fish back in.

KG: There is hysteresis; the system will not recover at same trajectory as it took to get there. Introduced (non-native) species can cause that. Returning to environmental conditions does not get rid of that introduced species. Another example is if you go past that point and cause extirpation of species that cannot recover.

**Q: Conclusions based on current data will be only as good as the data you have. You suggest data are sufficient for two fish and one bird. However, they are three species out of thousands. How confident then can I be as a land manager in your results as being useful for my decision process?**

PM: You can only do analyses for one critter at a time. And those are the critters for which there is data available. For thousands of others we have less or no data and the assessment of effects would be based on whatever information is available on them. I cannot think of a good way to describe the process of generating that assessment, other than best judgment and scientific thinking. We can do it by association in some cases; however, in most cases you are out of luck

KG: I think we actually have good community data for fish, and we have data on some other species, but the money is focused on threatened species. It would be ridiculous to consider a single species in a vacuum. The challenge is thinking outside a certain assemblage. Crayfish for example, or bullfrogs. They are not typically targeted but should be. A lot of recent work shows that fish influence the emergence of insects, which affects birds. It is a great question and a serious limitation.

PM: In some environment protection agency dealing with water quality standards, they have looked at a suite of organisms and identified the most sensitive organisms to certain toxicants. They might look at the most sensitive life feature. In that instance, they look at very conservative controls on water chemistry as a result of addition of toxins to a piece of water. The approach to assess effects of water withdrawal usually targets species that have a relevance to the situation, which is usually species that are endangered. That is why they rise to the top. They may not be the most sensitive to perturbation or changes in the system. It is a good question, what about the literally thousands of others.

RR: You can try to find indicator species that represent large groups of other species. They are not exact. Another approach is to monitor habitat. This includes for birds, invertebrates, reptiles, and mammals. Are trees regenerating? If we are not getting regeneration of cottonwoods, we know there are going to be changes. There can be preemptive measures, actions in the short term to help in the long term. The assumption is that this is probably going to be in maintaining viable population of species. As you go up in trophic levels – vegetation, then something feeds on vegetation (herbivore), then carnivore – we cannot monitor all species, we have to target a species. Indicator species are an approach. Also, we have to look at vegetation, the physical and biological matrix in which these species live, and assess based on that.

BG: This question is, why should I trust you when you are missing all the other 997,000 species? I think that is an important question. Science should be done in full contact with stakeholders so they are involved in all steps of the process. That way, they understand what is being done, why it is being done, how it is being integrated, and the assumptions of the models. That must be part of this. As an example from yesterday's tour, Dave Ogilvy participated in that kind of full contact that needs to take place across the watershed (interaction with studies on the Southwestern willow flycatcher).

**Q: Do you see benefits in multiple experts and disciplines working together (to assess effects of flow modification) vs. paying consultants to provide data?**

BF: We have been advocating synthesis for the pieces to fit together and explore the ways they fit together. A fragmented approach will not allow for a framework that will allow simultaneous assessment.

RR: I do not think there is a problem with having consultants, but there has to be a group that is bringing information together. It would hurt if there were no facilitating group.

WO: Within USGS, we have a critical-mass approach with several groups: groundwater chemistry, groundwater hydrology, surface-water chemistry, surface-water hydrology, ecology, and geomorphology and sediment transport. We are all put in the same padded cell, and we are forced to interact and have different approaches to what we are looking at. Universities are increasingly trying to tear down barriers among departments because the interaction between experts is good. There is a strong consensus that we need a group of people of different backgrounds.

BG: Thinking it through completely ahead of time can be very difficult. Look at the Yucca Mountain project – billions of dollars later and they are not building it. One thing that happened was that scientists found out over time that there were many things that could not be done within the plan that was thought through at the start. You need a plan that allows you to be flexible, so when you find out you are not getting anywhere or an area is unimportant, you can move. If you contracted that part out, then you do not have the flexibility to withdraw. You need a group that works well putting a system together.

RR: In a padded cell.

BG: And some stakeholders.

**Q: There seems to be a presumption that any hydrologic/geomorphic change will always cause adverse biological change. (1) How elastic are the biological systems? (2) Have existing hydro-physical modifications already exceeded the elasticity of the biological system?**

WO: Of course, change begets change. No dispute. But I would be hesitant to use the word adverse. There might be imposed change that will have positive changes. If we are going to be confident in predicting adverse changes, it may be when we cross thresholds. I would be cautious addressing a question of that sort. Change is not necessarily bad, if it is consistent with natural changes that already exist. We have to have that flexibility.

RR: Relative to the past, we have to look at the elasticity of the biological system. Elements that feed into that may be large portions of the river that have been heavily modified. There are things in the basin today that have had an effect, positive or negative. There are already things that have possibly reduced the resiliency. There are also things like climate change and landscape change; these are the kind of things that have to be looked at. These questions would be answered as part of this process and would feed back into whether there is room for project development or not.

**Q: It was my understanding that the scientific studies of the Gila River would inform the choice of which diversion (if any) would be least deleterious on the river we all love and depend on. What I heard today was that the scientists cannot study or predict the effects of flow modification until after a particular project is chosen. This is a conundrum, no? Can you help?**

BF: We are not exposed to any specific options, or alternative flow modification scenarios, so we cannot talk in any concrete way about the consequences of a scenario. If we were given a range, we could identify and rank what those alternatives were. We could say, these are most preferred and these the least preferred. This is what you would do with a synthetic model, but you cannot do it without specific information. We have not been advised of any considerations on the table.

WO: This is what we talked about at lunch. And we agreed that a disadvantage of a forum of this sort (one day) is that it constrains us to be able to take a look at the specific possibilities of the changes on the river due to diversion and to react specifically to different types of diversion. I think this is a shortcoming of not having enough time to do a decent job. That is a valuable question and with time and resources, we would like to do it.

RR: It seems we are mostly in agreement that aspirations and desired outcomes need to be identified and we can better understand and put together models. Then you could evaluate possible development. We still do not have aspirations and desired outcomes identified, and we cannot tell you what the outcomes are, even if we *did* know what the water diversion was. It would provide a roadmap to where these things will fall in place.

(General agreement among the panelists.)

BG: If we were given something like that, we would have a lively discussion on the spot, and we would want to build models to tease out dependencies and interdependencies. It is like applied vs. abstract math. In applied math, you are trying to solve specific equations/situations. There are constraints. A

lot of time, you sit there looking at an empty canvas and you can do nothing because it lacks constraints and sometimes we felt like that today.

KG: From the original hydrograph, you can change the timing, the flow, the frequency of space; there are just so many aspects. You could increase flows; flow modification is so hard to evaluate those different scenarios.

PM: It is also important to determine what it is that is important to you. There are thousands of species, some are important because they are protected, others because they have an important role in ecosystem. We can talk about flow modification effects from severe to not so severe, worst case to best case, and scale those according to this kind of effect. There is far more gray than many people would prefer. They would like black and white. The bottom line for water development, perhaps what stakeholders want to know is, is it economically feasible, are there going to be environmental constraints? And other stakeholders are concerned with damage that may not be relevant but important to them. The parsimonious approach is the best approach.

**Q: Are you all familiar with other aspects around the Arizona Water Settlements Act and Gila River basin activities? Do you think these efforts are on the right track? The decision-making committee structure? Watershed treatments?**

BG: I have knowledge of some of that. I thought they were on the right track until funding was cut by Governor Richardson - a systems approach to looking at the watershed. I am not involved. What I can say is that the model that has been developed has a lot of details for the decision-making process of the CUFA and a lot of other fairly broad components. What are missing are the ecological components and a full systems approach that starts from a set of aspirations. I think that model can be learned from. There is a paper in review at the Gila natural history conference that gives you an idea of what has been accomplished.

#### FINAL COMMENTS – PANELISTS

PM: I think we could have been more constructive if we had a good idea or better or an idea of the nature of the project. Are we talking about a structure or off-channel storage? Knowing what is meant by flow modification is just as important to the process as determining the effects. In a few hours, we could give a fairly comprehensive list of potential effects. Whether they would be realized would take more investigation. Personally, I wish I could have been more constructive, and I feel I let some of the audience down by not being able to provide more specific answers. I am not in your head and I do not know the specifics. We were given general questions.

RR: I can echo the concern and frustration, but I hope that people got something out of this in terms of perhaps stepping back a little bit and putting things into a bigger framework, toward an approach that can be jumpstarted quickly. Data to be collected should come out of analysis. We do not know the effects of flow modification because we do not know the type and we do not know people's values. Identifying these will help the process move faster than having us do something like this. Some of these modeling approaches are pretty important and have been successfully used in other places. You want to provide a format in which everyone can be involved.

WO: I would like to suggest that with the upper Gila River you have a remarkable resource, one of the few in the US that has not been heavily changed. It provides a control for future studies. I hope that will be kept in mind for the future. Whatever changes are put into effect, let us hope they are done with lots of research and wisdom.

KG: My important lesson is that the fish and the bird are, and this system is, operating as naturally as any Southwestern river system. I do urge an extreme amount of caution in modifying it. A key point was mitigation, but returning, the chronology. The changes in land use need to occur first before flow modification.

BF: Briefly, I want to emphasize that it is a unique resource because it is relatively untouched. It is unique from a scientific standpoint because there are a lot of data. That is not the case elsewhere. For example, for the Pacific Northwest forest plan they had to go out and get the data. In this system, there are a lot of data. Think about compiling and synthesizing that information into a framework. This system would allow for a synthetic assessment of different concerns – biological, ecological, and social – and this is a unique position from which to move forward.

BG: I want to thank the rest of the panel for making my points. And to thank everyone for inviting us. These meetings are really fun for the panelists because we get to interact with different people and respond on the spot. All my comments were made without the expressed consent of my funders or employer! Please place yourself in the context of the world around you. No man is an island. Look beyond. People are out there and they will place demands on you in the future. What you implement will have to withstand the test of time and assaults and you do not want this environment to degrade.

#### FINAL COMMENTS – AUDIENCE

Audience member: In the 2006 science forum, conclusions included the following. Does this panel agree? Anything new? (1) The process needs to include ecological, cultural, and economic assets. (2) Integrate science: flows shape the habitat, systems, biology, and species connectivity. Changing flow favors non-indigenous species. Consider human effects. (3) Engage stakeholders.

WO: From my limited knowledge, that is correct, except we went through a lot of different topics. If we had more time, we would come up with more.

Audience member: When we consider what we are going to do to the Gila, it has had a tough last century and a half. I look at it as a patient who has just risen from his hospital bed on crutches. What I have seen in the last decade and a half, the patient has been undergoing recovery. It is relatively pristine. We are not necessarily just looking at the baseline, but the river system is just now regaining the capacity to recreate wetlands. When you talk about sensitivity, it is the first thing to go. It is just now regaining wetland capacity. It is starting to reform a new floodplain at a new level. What is this river capable of? What did it look like in prehistoric times? Nobody knows, but it is worth it to understand what the potential of this river is. Are we measuring what is currently there? A hospital patient or a fully healthy individual?

WO: I think you are entirely right; with a 100-year history of interacting with humans, it was on a life support system and is moving off now. Some of the changes that are evident are absolutely diagnostic in saying there were thresholds that have been exceeded, even if we can identify a healthy river system, those thresholds were crossed and we will not have those same systems we had in the past. It will not be the same as 1850.

Audience member: A lot of people could not come today but will watch the Forum on public access TV. On the question of aspirations, we do have goals stated, and they are a compromise among the range of people attending. There are some whose main concern is to prevent water from going downriver and being used by someone else, and other people's main concern is protecting the river. Your forum was somewhat anachronistically scheduled. There is a range of projects being developed

by a group of stakeholders. We could make the list available to the panelists. . . . Thank you for coming.

Audience member: I just wanted to request that the panel, as it writes its report, be specific with suggestions, because a lot of them are similar to two years ago. We were not able to take that and move forward. Maybe we need more discrete advice.

## Appendix – Panelists' Bios

### William F. Fagan

#### Education:

Ph.D. in Zoology, University of Washington, Seattle, Washington, 1996. Advisor: Dr. Peter M. Kareiva.

Postdoctoral Associate, National Center for Ecological Analysis and Synthesis, Santa Barbara, California (1996).

#### Appointments:

Professor, Dept. of Biology, University of Maryland, College Park, Maryland (2008 – Present)

Associate Professor, Dept. of Biology, University of Maryland, College Park, Maryland (2002 – 2008)

Guggenheim Fellow (2001-2002)

Assistant Professor, Department of Biology, Arizona State University, Tempe, Arizona (1997 – 2002).

#### Major Research Interests Relating to SW Aquatic Systems:

Spatial ecology, particularly 1) how the geometry of riverine networks influences population persistence and community dynamics and 2) how species occupancy patterns and population size relate to their risk of extinction.

#### Key Publications Relating to SW Aquatic Systems

Muneepeerakul, R., E. Bertuzzo, H. Lynch, **W. F. Fagan**, A. Rinaldo, and I. Rodriguez-Iturbe. 2008. Fish diversity patterns in Mississippi-Missouri basin support neutral metacommunity models. **Nature**, 453: 220-3 (plus 9 pages of on-line material).

Grant, E.H.C., W. Lowe, and **W.F. Fagan**. 2007. Living in the branches: population dynamics and ecological processes in dendritic networks. **Ecology Letters**. 10: 165-175 (**Cover Article**)

Sheller, F.J., **W.F. Fagan**, and P.J. Unmack. 2006. Analyzing translocation success from sporadic monitoring data using survival analysis: Lessons from the Gila topminnow (*Poeciliopsis occidentalis*). **Ecological Applications**. 16: 1771-1784.

**Fagan, W.F.**, and E. E. Holmes. 2006. Quantifying the extinction vortex. **Ecology Letters**. 9: 51-60.

**Fagan, W.F.**, C.M. Kennedy, and P.J. Unmack. 2005. Quantifying rarity, losses, and risks for lower Colorado River Basin fishes: Implications for conservation listing. **Conservation Biology**. 19: 1872-1882.

Kuby, M.J., **W.F. Fagan**, C. ReVelle, and W. Graf. 2005. A multiobjective optimization model for dam removal: An example trading off salmon passage with hydropower and water storage in the Willamette basin. **Advances in Water Resources**. 28: 845-855.

**Fagan, W.F.**, C. Aumann, C.M. Kennedy, and P.J. Unmack. 2005. Rarity, fragmentation and the scale-dependence of extinction-risk in desert fishes. **Ecology** 86: 34-41. (**Cover Article**)

Unmack, P.J. and **W. F. Fagan**. 2004. Convergence of differentially invaded systems toward invader-dominance: time-lagged invasions as a predictor in desert fish communities. **Biological Invasions**. 6: 233-243.

Eby, L.A., **W.F. Fagan**, and W.L. Minckley. 2003. Variability and dynamics of a desert stream fish community. **Ecological Applications**. 13: 1566-1579.

Holmes, E. E. and **W.F. Fagan**. 2002. Validating population viability analysis for corrupted data sets. **Ecology**. 83: 2379-2385.

**Fagan, W.F.** 2002. Fragmentation and extinction risk in dendritic metapopulations. **Ecology**. 83: 3243-3249. (**Cover Article**).

**Fagan W.F.**, P. Unmack, C. Burgess, and W.L. Minckley. 2002. Rarity, fragmentation, and extinction risk in desert fishes. **Ecology**. 83: 3250-3256. (**Cover Article**)

**Keith B. Gido****Education:**

Ph.D. in Zoology, University of Oklahoma, Norman, Oklahoma, 1999. Advisor: Dr. William J. Matthews  
Postdoctoral Associate, Sam Noble Museum of Natural History, Norman, Oklahoma, 2001

**Appointments:**

Associate Professor, Dept of Biology, Kansas State University, Manhattan, Kansas (2005-present)  
Assistant Professor, Dept of Biology, Kansas State University, Manhattan, Kansas (2002-2005)

**Major Research Interests:**

My research has focused on the conservation of aquatic systems in the western and central U.S. These efforts can be classified into three general areas: 1) evaluation of patterns and processes regulating species diversity and habitat associations of fishes, 2) effects of global climate change on stream ecosystem function, and 3) species relationships in non-coevolved fish assemblages.

**Primary Publications on Aquatic Systems of Southwest & Central US:**

Propst, D.L., **K.B. Gido** and J.A. Stefferud. 2008. Natural flow regimes, nonnative fishes, and persistence of native fish assemblages in arid-land river systems. *Ecological Applications* 18:1236-1252.

Franssen, N.R., **K.B. Gido** and D.L. Propst. 2007. Flow regime affects availability of nonnative prey of an endangered predator. *Biological Conservation* 138:330-340.

**Gido, K.B.** and N.R. Franssen. 2007. Invasion of stream fishes into low trophic positions. *Ecology of Freshwater Fishes* 16:457-464.

Franssen, N.R., **K. B. Gido**, T. R. Strakosh, K. N. Bertrand, C. M. Franssen, C. P. Paukert, K. L. Pitts, C. S. Guy, J. A. Tripe, S. J. Shrank. 2006. Effects of floods on fish assemblages in an intermittent prairie stream. *Freshwater Biology* 51: 2072–2086

**Gido, K.B.**, N.R. Franssen\*, and D.L. Propst. 2006. Spatial Variation in  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  Isotopes in the San Juan River, New Mexico and Utah: Implications for the Conservation of Native Fishes. *Environmental Biology of Fishes* 75:197-207.

**Gido, K.B.**, J.A. Falke, R.M. Oakes, and K.J. Hase. 2006. Fish-habitat relationships across spatial scales in prairie streams. Hughes, B., P. Seelbach, and L. Wang (eds.) *Influences of Landscapes on Stream Habitats and Biological Communities*, American Fisheries Society Symposium 48:265–285.

Schaefer, J., **K. Gido** and M. Smith. 2005. A test for community change using a Monte-Carlo approach. *Ecological Applications*: 15:1761-1771

Propst, D.L. and **K. B. Gido**. 2004. Responses of Native and Nonnative Fishes to Natural Flow Regime Mimicry in the San Juan River. *Transactions of the American Fisheries Society* 133:922-931.

Gido, K. B., C. S. Guy, T. R. Strakosh, R. J. Bernot, K. Hase, and M. Shaw. 2002. Long-term changes in the fish assemblages of the Big Blue River basin 40 years after the construction of Tuttle Creek Reservoir. *Kansas Academy of Sciences Transactions* (Frank Cross Memorial Issue) 105(3-4):193-208.

**Gido, K. B.** and J. H. Brown. 1999. Invasion of alien fish species in North American drainages. *Freshwater Biology* 42:387-398.

**Gido, K. B.**, D. L. Propst, and M. C. Molles, Jr. 1997. **Spatial** and temporal variation of fish communities in secondary channels of the San Juan River, New Mexico and Utah. *Environmental Biology of Fishes* 49:417-434.

### Robert J. Glass

Dr. Robert J. Glass received his BS from Haverford College in 1980 with a self-designed major in biology-ecology and course work at Haverford, Bryn Mawr and Swarthmore Colleges, and the University of Pennsylvania. After two years in the tropics where he conducted research in a variety of ecosystems, he continued his education at the Yale School of Forestry & Environmental Studies and then at Cornell University's Department of Agricultural and Biological Engineering where he received his MS in 1985 and Ph.D. in 1988 with emphases on experimental, analytical, numerical and field research methods applied to address problems of fluid flow and chemical transport in environmental systems, e.g. soil, rock formations, groundwater, lakes, streams, atmosphere, and oceans.

Dr. Glass joined Sandia National Laboratories in 1988 where he led the unsaturated zone model development and validation task for the Yucca Mountain Project, the goal for which was to design and build the US's repository for high-level nuclear waste. From 1988 until 2003, his research, funded through a variety of programs at the Department of Energy, covered wide-ranging topics in arid region vadose zone hydrology, groundwater hydrology, multi-phase and multi-component transport, and large scale transport pathway delineation in glacial till, alluvial sediments and fractured rock. During this period, Dr. Glass created the Flow Visualization and Processes Laboratory (FVPL) at Sandia where he, colleagues and students developed and applied state of the art visualization methods to illuminate the fundamental temporal and spatial structure of subsurface flow and transport. These experiments led to extended theory and models for vadose zone flow and transport, fingering, multi-phase and multi-component transport instabilities, the delineation of Dense Non Aqueous Phase Liquids (DNAPLs) within aquifers, and to the application of complexity science to infiltration cascading in fractured rock networks such as at Yucca Mountain, Nevada. Dr. Glass achieved the Sandia Distinguished Level for these efforts in 1998.

In 2003, Dr. Glass joined the National Infrastructure Simulation and Analysis Center (NISAC), a joint center between Sandia and Los Alamos National Laboratory funded by the Department of Homeland Security. There, he has grown a research team that focuses on the analysis and control of complex interdependent adaptive systems as embodied by many critical infrastructures and human systems. Example applications include the design of robust community containment strategies for pandemic influenza, the role of international coordination in the management of large value payment systems (e.g., the U.S. Federal Reserve's Fedwire system and the European Union's TARGET system), and the enhancement of national and international energy surety in context of global carbon treaties. This work has formed the foundation for a new initiative at Sandia in Complex Adaptive Systems of Systems Engineering.

Dr. Glass has held Adjunct Professor appointments at the University of Colorado, New Mexico Institute of Mining and Technology, University of Nevada, University of New Mexico and most recently at the Uniformed Services University of the Health Sciences in Bethesda, Maryland. In connection with these and other universities from across the country and abroad, he has taught graduate classes and seminars, advised graduate research (12 PhD, 4 MS) and incorporated undergraduates into research (over 25). He has authored or co-authored: more than 70 journal articles; 15 book chapters or symposium series papers, 50 reports or papers in conference proceedings; 50 invited presentations at conferences, universities and other research institutions; and 125 contributed presentations at conferences. Dr. Glass was the head Coordinator for the Upper Gila River Science Forum, held October 21-22, 2006.

**Paul C. Marsh****Education**

Ph.D., Fisheries, University of Minnesota, 1979.  
Major Professor: Dr. Thomas F. Waters

**Professional Appointments**

Owner, Marsh & Associates, LLC (Arizona), 2006-present  
Faculty Research Associate, School of Life Sciences, Arizona State University, 1997-2008  
Professor, Associate Professor, and Assistant Professor of Research, Center for Environmental Studies, Arizona State University, 1981-1997  
Research Ecologist, Arizona State University, 1980-81

**Research Interests**

Biology and conservation of southwestern native fishes; dynamics of imperiled species populations; predation as a deterrent to species recovery; artificial habitats for long-term management of threatened and endangered fishes; novel strategies to conserve fishes.

**Selected Publications Related to Southwestern Aquatic Systems**

- Marsh, P. C.**, and W. L. Minckley. 1982. Fishes of the Phoenix metropolitan area in central Arizona. *North American Journal of Fisheries Management* 4: 395-402.
- Meffe, G. K., and **P. C. Marsh**. 1983. Distribution of aquatic macroinvertebrates in three Sonoran desert springbrooks. *Journal of Arid Environments* 6: 363-371.
- Marsh, P. C.** 1985. Effect of incubation temperature on the survival of embryos of native Colorado River fishes. *The Southwestern Naturalist* 30: 129-140.
- Marsh, P. C.** 1987. Digestive tract contents of adult razorback suckers in Lake Mohave, Arizona-Nevada. *Transactions of the American Fisheries Society* 116: 117-119
- Marsh, P. C.**, and S. G. Fisher. 1987. Metabolism of an arid region canal ecosystem. *Journal of Arid Environments* 12: 255-267.
- Marsh, P. C.**, and D. R. Langhorst. 1988. Feeding and fate of wild larval razorback sucker. *Environmental Biology of Fishes* 21: 59-67.
- Dowling, T. E., B. D. DeMarais, W. L. Minckley, M. E. Douglas, and **P. C. Marsh**. 1992. Use of genetic characters in conservation biology. *Conservation Biology* 6: 7-8.
- Douglas, M. E., **P. C. Marsh**, and W. L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement: *Meda fulgida* (Cyprinidae) as a case study. *Copeia* 1994: 9-19.
- Douglas, M. E., and **P. C. Marsh**. 1996. Population estimates/population movements of *Gila cypha*, an endangered cyprinid fish in the Grand Canyon region of Arizona. *Copeia* 1996: 15-28.
- Garrigan, D., **P. C. Marsh** and T. E. Dowling. 2002. Long-term effective population size of three endangered Colorado River fishes. *Animal Conservation* 5: 95-102.
- Minckley, W. L., **P. C. Marsh**, J. E. Deacon, T. E. Dowling, P. W. Hedrick, W. J. Matthews, and G. Mueller. 2003. A conservation plan for native fishes of the lower Colorado River. *BioScience* 53(3): 219-234.
- Mueller, G.A. and **P.C. Marsh**. 2003. Lost, a Desert River and Its Native Fishes: An historical perspective of the lower Colorado River. U.S. Geological Survey, Denver, CO.
- Marsh, P.C.**, B.R. Kesner, and C.A. Pacey. 2005. Repatriation as a management strategy to conserve a critically imperiled species. *North American Journal of Fisheries Management* 25: 547-556.
- Clarkson, R.W., **P.C. Marsh**, J.A. Stefferud and S.E. Stefferud. 2005. Conflicts between native and sport fish management in the southwestern United States. *Fisheries* (Bethesda, Maryland) 30: 20-27.
- Minckley, W. L., and **P. C. Marsh**. 2009. *Inland Fishes of the Greater Southwest: Chronicle of a Vanishing Biota*. The University of Arizona Press, Tucson.

**Waite R. Osterkamp****Current Position:**

Research Hydrologist, Emeritus, Geomorphology and Sediment Transport, National Research Program, Water Resources Discipline, USGS, 1955 E. 6<sup>th</sup> Street, Suite 115, Tucson AZ 85719; affiliated with Southwest Watershed Research Center, Agricultural Research Service, USDA, Tucson, AZ; Adjunct Professor, University of Arizona, Tucson, AZ; Adjunct Professor, University of Denver, Denver, CO.

**Education:**

University of Arizona, Ph.D., 12-76, Geology/Hydrology  
University of Arizona, M.S., 6-70, Geology/Hydrology  
University of Colorado, B.A., 6-63, Chemistry  
University of Colorado, B.A., 6-61, Geology

**Experience:**

Project Chief, Sediment Impacts from Disturbed Lands, National Research Program, WRD, USGS, 1980-2008; Adjunct Professor, University of Arizona, 1996-present; Adjunct Professor, University of Denver, 1995-present; Visiting Scientist, Agricultural Research Service, Tucson AZ, 1991-93; Research Advisor, Geomorphology and Sediment Transport Discipline, NRP, WRD, USGS, 1991-92 and 2002-2003; Adjunct Professor of Geology, George Mason University, Fairfax, VA, 1984-87; Hydrologic and geomorphic studies, USGS, Lawrence, KS, 1974-80; Hydrologic and geologic studies, USGS, Tucson, AZ, 1971-74; Teaching Assoc., University of Arizona, 1970-71; Research Assist., University of Arizona, 1969-70; Water-quality studies, USGS, Helena, MT, 1966-68; Hydrologic and geologic studies on public lands, USGS, 1961-66.

**Affiliations and Selected Activities:**

Geological Society of America (Fellow)  
International Association of Hydrological Sciences  
International Association of Sedimentologists  
American Association for the Advancement of Science  
American Geophysical Union  
Binghamton Geomorphology Symposium Steering Committee  
American Quaternary Association  
International Union of Geological Sciences  
Consultant, Department of Justice and U. S. Fish and Wildlife Service, litigation for the adjudication of water, Snake River, Idaho  
Board of Directors, The Research Ranch Foundation, Appleton-Whittell Research Ranch

**Awards and Recognition**

Marsico Visiting Scholar, University of Denver, Autumn Quarter, 2005  
Outstanding Dissertation Advisor, School of Natural Resources, University of Arizona, 2004, 2005  
USDI Meritorious Service, 2002

**Bibliography (selected papers)**

- Osterkamp, W. R.**, and Hedman, E. R., 1977, Variation of width and discharge for natural high-gradient stream channels: *Water Resources Research*, v. 13, no. 2, p. 256-258.
- Osterkamp, W. R.**, 1978, Gradient, discharge, and particle-size relations of alluvial channels of Kansas, with observations on braiding: *American Journal of Science*, v. 278, p. 1253-1268.
- Osterkamp, W. R.**, and Hedman, E. R., 1982, Perennial-streamflow characteristics related to channel geometry and sediment in Missouri River basin: *U. S. Geological Survey Professional Paper 1242*, 37 p.
- Osterkamp, W. R.**, Lane, L. J., and Foster, G.R., 1983, An analytical treatment of channel-morphology relations: *U. S. Geological Survey Professional Paper 1288*, 21 p.
- Osterkamp, W. R.**, and Hupp, C. R., 1984, Geomorphic and vegetative characteristics along three northern Virginia streams: *Geological Society of America Bulletin*, v. 95, p. 1093-1101.

- Osterkamp, W. R.**, and Costa, J. E., 1987, Changes accompanying an extraordinary flood on a sand-bed stream, In: Mayer, L., and Nash, D. (eds.), *Catastrophic Flooding*: Allen & Unwin, Boston, p. 201-224.
- Osterkamp, W. R.**, 1998, Processes of fluvial-island formation, with examples from Plum Creek, Colorado, and Snake River, Idaho: *Wetlands*, v. 18, no. 4, p. 530-545.
- Osterkamp, W. R.**, and Friedman, J. M., 2000, The disparity between extreme rainfall events and rare floods -- with emphasis on the semiarid American West: *Hydrological Processes*, v. 14, no. 16-17, p. 2817-2829.
- Briggs, Mark, and **Osterkamp, W. R.**, 2003, Developing recovery plans for riparian ecosystems: *Southwest Hydrology*, v. 2, no. 2, p. 18-19.
- Briggs, Mark, and **Osterkamp, W. R.**, 2003, Important concepts for riparian recovery: *Southwest Hydrology*, v. 2, no. 2, p. 26.
- Osterkamp, W. R.**, 2004, Bankfull discharge, In Goudie, A. S. (ed.), *Encyclopedia of Geomorphology*: Routledge, London, p. 52-54.
- Lopes, V. L., **Osterkamp, Waite R.**, and Bravo-Espinosa, Miguel, 2007, A method for improving predictions of bed-load sediment transport to reservoirs: *Lakes & Reservoirs: Research and Management*, v. 12, p. 59-72.
- Osterkamp, W. R.**, 2008, Annotated definitions of selected geomorphic terms, and related terms of hydrology, sedimentology, soil science, climatology, and ecology: U. S. Geological Survey Open-file Report 2008-1217, 49 p.
- Osterkamp, W. R.**, and Marlow, J. E., 2008, Southern Arizona's native grasslands: understanding and valuing their ecosystem services: The Research Ranch Foundation and The Sonoran Institute, Tucson, AZ, 4 p.
- Osterkamp, W. R.**, and Marlow, J. E., 2008, Water, Conservation, and Exurban Development in Semiarid Grasslands of Southwestern North America – Impacts on Biodiversity and Ecosystem Services: The Research Ranch Foundation in collaboration with The Sonoran Institute, Tucson, AZ, 36 p.