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Return Flow Efficiency

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This morning I'd like to start with talking about the hydrology of riparian systems, although I will touch a bit on some non-riparian systems. When trying to think of a good analogy for this topic, I first thought that explaining this is like explaining derivative securities, but then there are some things you shouldn't joke about. But now I'm thinking that really is a good analogy, all joking aside.

First let's start with a few definitions, beginning with consumptive loss. A consumptive loss is water that is lost or removed from the local hydrologic system where it essentially goes over and rains on Texas, it is gone from here and we have no more access to it or it becomes unusable for other reasons. I am going to simplify this as much as I can, but there are also issues concerning locations of returns that we will get into in a bit.

Secondly we have non-consumptive losses, water that is removed from a control or delivery system, but not lost to the local hydrologic system. An example would be a canal system where you have a little control over seepage that recharges the local groundwater system but it just changed from surface water to groundwater.

Return flow is water that is diverted from a source that is not consumed and can be reused. This could be water from a river or aquifer system that is not consumed and can be reused and essentially recaptured by the local hydrologic system.

Finally, when we talk about return flow efficiency, we are talking about the ratio of the actual return flow: the amount of water that is actually reused and returned to the source to the non-consumptive losses. Think of the non-consumptive losses as potential return flows; whether or not they actually make it back is another issue.

I will start with an example that is adapted from a 1996 paper David Seckler presented and this concept goes back long before that. You find the same concept of the return flow built into the Rio Grande Compact and you find it in irrigation texts dating back to the 1930s. It is an old concept but often one that gets kind of swept under. We have inflow into a source (Fig. 1), let's say the Rio Grande is the source. If someone takes a 50 gallon shower, they turn on their shower, 50 gallons comes out of the source, the water then goes into a surface water treatment plant, and then back to the shower. But that's not the end of it. Of course we have drain flows and the example I cite here has a return flow efficiency of 100 percent. That drain flow is the potential non-consumptive loss, it goes to the wastewater treatment plant, which then returns it to the source. The net impact on the source in this case is zero. We took 50 gallons out and put 50 gallons back in. However, if I put a low-flow shower head on that shower, again assuming 100 percent return flow efficiency, and I only have a 25 gallon shower, I only take out 25 gallons, and I only treat 25 gallons of wastewater, yet the net impact on the river is precisely the same.

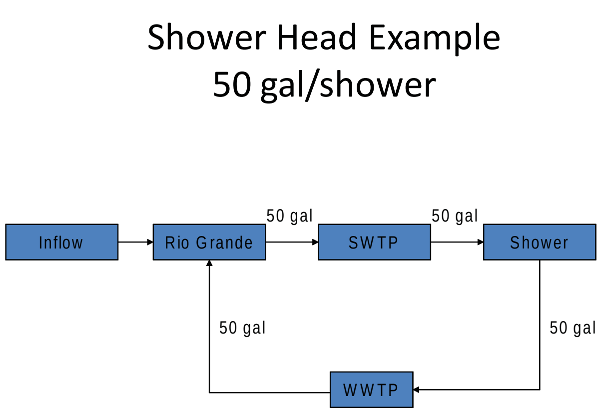

Figure 1. Shower Head Example

Now you might say there are some consumptive losses here, the water that you dry off with your towel for example, but I would maintain that is the same amount of water whether you take a 50 or 25 gallon shower. In fact, what we are looking at in most of these discussions is a differential analysis: the difference between some existing management measure and some water conservation, some improved water management measure.

Taking this same kind of generalized hydrologic approach, I have been trying to develop a generalized irrigation hydrology and I don't think I am done with it yet (Fig. 2). First, we have our inflow to a source. The inflow may be natural recharge or it may be snowmelt runoff, but the source is essentially a river, an aquifer, or a river/aquifer system. We have consumptive losses that occur directly from the source and we also have non-consumptive losses during conveyance. The non-consumptive losses, if we are talking about a riparian irrigation system, would primarily be canal seepage. It is a very big loss, but there are also losses from operational spills. Excess water within the canal system is dumped directly back to the river without ever going through the seepage process. We then apply the water to the field, which is the real objective — diverting the water down to the field and, of course, we have very significant consumptive use here. That is different from the shower example, however, this is not a bad thing. That consumptive use is what drives the yield formation, that's why you irrigate, that's what provides the economic production of the whole system. We also have non-consumptive uses on the farm, for example, deep percolation, and runoff. These non-consumptive losses from conveyance and application have some losses associated with them but whatever isn't lost in return to the source, goes back to the source and the ratio between what is actually showing up in the source against non-consumptive losses is the number I am calling "return flow efficiency."

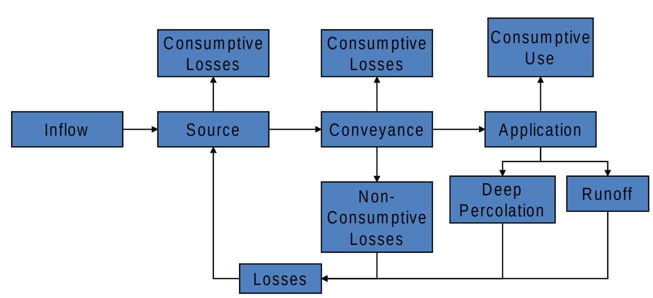

Figure 2. Generalized Irrigation Hydrology

Let's look at riparian irrigation systems. I have worked on a few of them around the state and since there is no such thing as a typical irrigation system, I'm not calling these typical, but I think most of what I'm going to say later applies to these systems. The primary source of non-consumptive losses (potential return flow) is canal seepage. I know for a fact that this is the largest potential source in the Elephant Butte Irrigation District (EBID). I'm not quite sure about the Middle Rio Grande but it is a big non-consumptive loss there also.

Another source of non-consumptive losses is operational spills where excess water diverted into the canal system is dumped directly back to the river. And the third source is deep percolation where excess water applied to the field percolates through the root zone to the local groundwater. If the excess water doesn't percolate through the root zone, we assume the plant gets all of it and uses it for evapotranspiration as a consumptive use to generate yield. In these systems, we have a relatively high return flow efficiency.

I haven't quite figured out all the details yet on this concept, but if we look at, for example, the drain flows in the Middle Rio Grande relative to the diversions, it's a pretty significant amount. But there are other return flows that are not measured in the Middle Rio Grande. We obviously have the drains that return water at discrete points, which can be measured. We also have deep percolation that recharges the hydrologically connected aquifer and that is a whole lot harder to measure. The returns that do go back into the river can be reused by industrial water users or they can be used to meet downstream water delivery obligations. There is also groundwater pumping in these systems. The primary source of recharge is these potential return flows. This is one of the things I haven't quite worked out in my mind: does groundwater recharge constitute actual return flow that was captured and reused? I tend to think, probably, yes.

If we look at a few water conservation measures in terms of these hydrologic components, let's see what they really address. First, canal lining primarily reduces seepage, a non-consumptive loss. Recently EBID lined about 22-23 miles of canals, and that has resulted in a reduction of seepage. No, that doesn't mean that you shouldn't line canals. Let me make that clear. I think there are canals that really need to be lined — canals that are used intermittently and perhaps have very high seepage rates. It's true seepage is not lost, but it's requiring excessive deliveries to the lateral in order to fill up, make the delivery, and then drain. So there are timing and management issues aside from the recharge. However, I hope most of the districts are not going into heavy canal lining phases because of their downstream considerations. As Steve Vandiver said in Colorado, they got a little too tight on their water conservation measures and they conserved themselves right out of an aquifer.

If we look at on-farm irrigation technologies like advanced high efficiency measures through drip and flood irrigation and LEPA, what they are really focusing on is non-consumptive deep percolation as the primary reduction. They may reduce the incidental evaporative losses, a consumptive loss. For example, if you are flood irrigating, you reduce the evaporation that takes place during flooding particularly before you have a full crop cover. So there is some effect on consumptive use but, in fact, what you are really doing is reducing your non-consumptive losses. For lower water use crops, this is a case where we really are reducing both applied water and consumptive losses. The trouble is that people don't pick their crops solely on the basis of how much water they use. However, the number one criteria for crop selection is whether someone can make any profit from the crop. There are many other considerations that go into a crop selection other than water use.

Another aspect to look at is forbearance. Back in 2005, Dr. Ronachan Odiff of Colorado State University and I did a small study for the Middle Rio Grande and looked at the effect of forbearance on making water available for in-stream management of silvery minnows. It was a very interesting study and we found that forbearance had both consumptive and non-consumptive impacts. A nice summary of what we determined is in Figure 3.

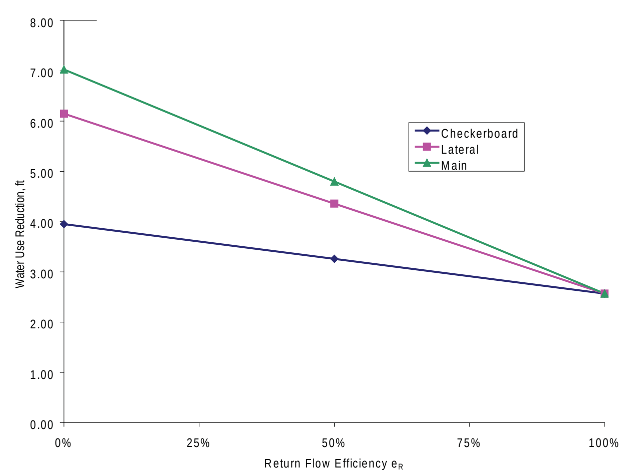

Figure 3. Return Flow Efficiency and Forbearance

There is return flow efficiency in the Middle Rio Grande no matter how you calculate it. It is a very complicated: you have the Bosque taking some of the potential return flow out, you have groundwater pumping, you have all sorts of things going on. Many of the drains aren't very well metered, so it is hard to assess what the actual return flow is and what the potential return flows are as well. We estimated the canal seepage and deep percolation from irrigation, and we may both be PhDs, but what we determined was that the return flow efficiency would be somewhere between 0 and 100 percent. That is to say, it is possible that all of the potential return flow makes it back, or that none of it makes it back, but it will probably not be outside of that range.

What we did was to look at the different strategies of forbearing water and let me explain what these are. You can provide incentives for farmers to forebear; you get one farmer here and one farmer there, not contiguous, not organized, just whoever will buy into the program. That is the checkerboard effect as shown in Figure 3. The lateral effect is where you get all the farmers on an entire lateral to enter into the forbearance program. The main effect is where you get everyone in a main river diversion unit out — how much water would be saved per acre of forbearance? You can see that if we assume a return flow efficiency of 100 percent, that is all available non-consumptive losses are getting back to the river and are available for downstream use, that all you save is the consumptive irrigation requirement. You don't get credit for any of those non-consumptive losses because, again, we are looking at it as a differential. Even if you take those areas out of production, there is still somebody downstream that is expecting that quantity of water and has a right to it. If we assume that none of the water makes it back, down at the zero end, you will notice that for the checkerboard system, what you get is the total applied water. We assume none of it makes it back and you save the total applied water. If you go to the lateral system, you save the entire application plus the losses within the lateral. And if you can take out an entire main system diversion, you get the whole diversion from the river. If you were diverting about 7 ft/acre as they were doing at the time we did this study, you would save all of that at 0 percent return flow efficiency. Somewhere between the space representing the loss of laterals and the on-farm losses, you have some semblance of reality and no doubt it changes dramatically with location and time. For simplicity, we assumed 50 percent. Why? Because it was between 0 percent and 100 percent.

Figure 4 is a diagram that I found useful, especially talking to civil engineers and explaining what a surface irrigation probe looks like. The diagram graphs the distance down the field from the head to the tail and after a surface irrigation event, the infiltrated profile. The blue line is a function of infiltrated depth as a function of distance down the field. At the far left, at the head of the filed, you have a little more than 4.5 inches infiltrated, and at the tail of the field you have about 3 inches. In this case, I am assuming a pre-irrigation deficit of 3 inches.

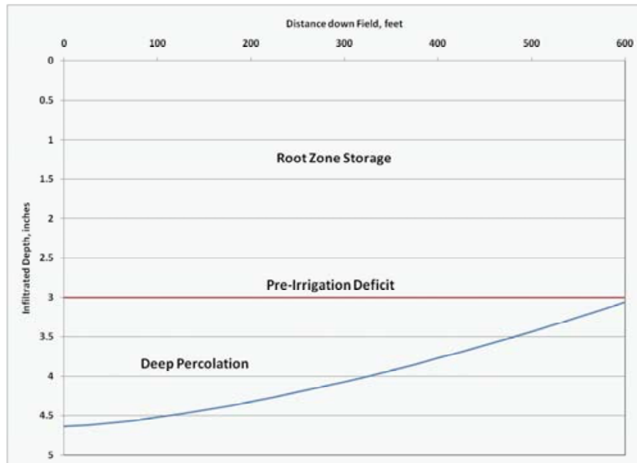

Figure 4. Basic Surface Irrigation Infiltration

What that means is that the root zone of the soil can hold 3 inches of water, anything in excess of that deep percolates. The reason you have more infiltration at the left of the graph than you have on the right side of the graph, is that you start watering from the left side. You have water at the left side the whole time you are pushing water down the field until you get to the right side. Thus, the water has been infiltrating on the left side longer than it has on the right side by the time it is over.

Suppose you improve your irrigation and you apply the water faster and for a shorter duration (Fig. 5). What that does is push the water down the field faster, thereby reducing the discrepancy between the head of the field and the tail of the field and lo and behold, you can apply less water, still get a full irrigation, and you have water left over. You actually apply less water in this case. What have you done? Before and after irrigating, you have reduced the deep percolation. Now if we look at Figure 5, instead of taking this excess water out, which reduces the return, assuming the losses would be unaffected by the change, you are reducing the recharge back to the source.

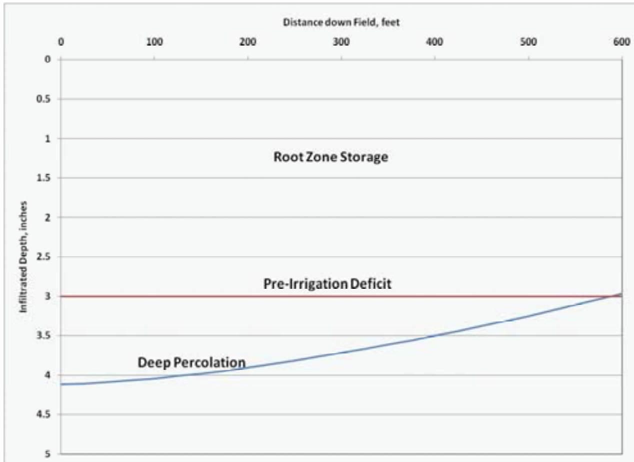

Figure 5. Improved Surface Irrigation Infiltration

Here is another fact of life: the more water a crop uses, the higher the yield. Take green chile as an example (Fig. 6). This figure was adapted from a study by Wierenga back in the late 1970s/early 80s, where he measured the amount of water consumed (actually this was water applied but it was a very high efficiency system so we take it as water consumed). You will notice that the more water a crop uses, the more yield you get. Well that's what farmers are supposed to do — use their resources as efficiently as possible and get the most yield they can out of it.

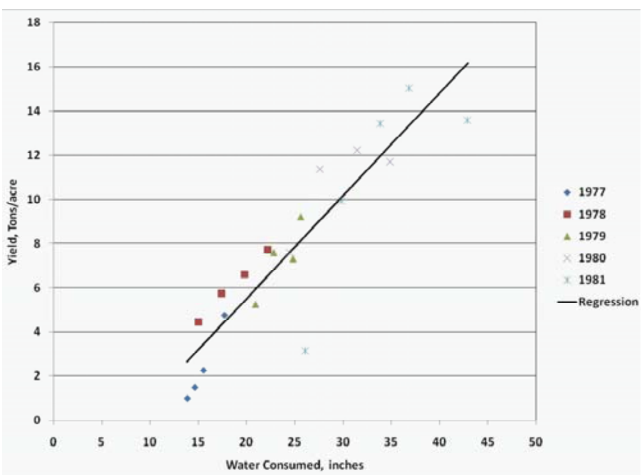

Figure 6. Water Production Function - Green Chile adapted from Wierenga, 1983

What happens if you reduce non-consumptive losses? If you have a fixed allotment and you use less water per irrigation, you can irrigate more. What that does is to make more water available for consumptive use. You get increased production and profit, which is exactly what you are trying to do. However you decrease the return flow, and this then has the potential for impairing downstream water rights.

Let's take a quick example (Fig. 7). If I have 3 feet on a traditional application with 65 percent application efficiency (I took Wierenga's relationship and found that it uses 23.4 for consumptive use, so the rest, 12.6, goes back for return flow), I get 7.1 tons/acre out of that function. If I upgrade my system to 85 percent application efficiency, I get 10.4 tons/acre. However, I have increased my consumptive use and decreased my return flow. And that is where you can get into problems — conserving yourself out of an aquifer or creating downstream problems. The net result is 3.3 increase in yield, 7.2 increase in consumptive use, and a 7.2 decrease in potential return flows.

Traditional Practice
- 3 ft
- 36 inches
- 65% application efficiency
- 23.4 inches consumptive use
- 12.6 inches potential return flow
- 7.1 tons/acre

Improved Practice
- 3 ft
- 36 inches
- 85% application efficiency
- 30.6 inches consumptive use
- 5.4 inches potential return flow
- 10.4 tons/acre

Net Result
- 3.3 tons/acre increase in yield
- 7.2 inches increased consumptive use
- 7.2 inches reduction in potential return flow

Alternative
- 76% of acreage planted
- 3 ft
- 36 inches
- 85% application efficiency
- 30.6 inches consumptive use
- 5.4 inches potential return flow
- 10.4 tons/acre
- 113% of traditional total yield

Figure 7. Chile Example

Here is an alternative, and this is what a person who is trying to convince the farmer to live within his means would suggest. If you use 76 percent of the total acreage, you actually have exactly the same depletion with the 85 percent efficiency that you would with the 65 percent. You are just stacking water on less land. You have 30.6 inches of consumptive use and the same amount of total volume, but you are using it on less acreage. You get 10.4 tons per acre, which even on 76 percent of the acreage, you end up with 113 percent of your traditional yield. That is the general sort of accountant's explanation of how we should go about handling this.

Now you do have conflicting perspectives. You have a statement that you have heard many, many times in many, many water presentations: "Beneficial use shall be the basis, the measure and the limit of the right to the use of water." But the ambiguity of the meaning of "beneficial" has long been argued. Nobody ever defined "beneficial." To tell you the truth, that is only the first part of the ambiguity: "use" — I hate to sound like Bill Clinton — but it depends on what your definition of "use" is. To a production irrigator, it means applied water. That's what irrigators work with, that's what they measure, that's what they are allotted, that's their currency. If you are dealing with a regulator or a manager who has to consider downstream impacts, what he is really trying to do is to maintain the hydrologic balance and equity among water users by manipulating the *applied* water that he allots for permits to users to control *consumptive* use. But as you see, they are not the same thing.

Here is a quick example. If you have mined groundwater such as what is on the east side of the state, you have a weak or long-term connection between the surface water and the groundwater. I liked John Shomaker's explanation: by the time the recharge gets there from the irrigation, the aquifer will be gone. Therefore, the return flow efficiency is very small in human time scales. Maybe if we wait until the next ice age, things will be better; some of that water will work its way down, but I don't think that is a functional business. Thus the reduction of these non-consumptive losses is generally less important. In other words, if you do improve your efficiency, and turn mined water straight into yield, that is a good thing. What you do in this example is a very different conceptual approach than from a riparian system.

The other quote you see at every water conference is from 11 Samuel 14:14, "...water spilt on the ground ... cannot be gathered up again." Of course you can!