Center for Water Resources Research
Annual Technical Report
FY 2007

Introduction

The Utah Center for Water Resources Research (UCWRR) is located at Utah State University (USU), the Land Grant University in Utah, as part of the Utah Water Research Laboratory (UWRL). It is one of 54 state water institutes that were authorized by the Water Resources Research Act of 1964. Our mission is related to stewardship of water quantity and quality through collaboration with government and the private sector. The UCWRR facilitates water research, outreach, design, and testing elements within a university environment that supports student education and citizen training. The UCWRR actively assists the Utah Department of Environmental Quality (UDEQ), the Utah Department of Natural Resources (UDNR), the State Engineers Office, all 12 local health departments, and several large water management agencies and purveyors in the state with specific water resources problems.

In FY 07, the UWRL expended a total of approximately $9 million in water research support. USGS Section 104 funds administered through the UCWRR accounted for about one percent of this total. These funds were used for research addressing water and wastewater management problems, outreach, information dissemination, strategic planning, water resources, and environmental quality issues in the State of Utah.

Three research projects were funded in FY 06 with funds from the 104−b program. These projects, respectively entitled "Development and Calibration of a Hydrodynamic Model for Utah Lake", "Economic and Fiscal Impacts of the Groundwater Management Plan in the Beryl−Enterprise Area", and "Two−Zone Temperature and Solute Model Testing and Development in the Virgin River", dealt with water management issues involving recovery of endangered species (in the Utah Lake drainage basin and in the Virgin River), and quantification and management of the economic consequences of changes in groundwater rights in Utah (in the Beryl−Enterprise area). The projects were implemented in three major river basins in Utah, and they involved collaboration of local, state, and federal water resources agency personnel.

Research Program Introduction

USGS Section 104 funds were used to address temperature−related issues related to management of endangered species in the Virgin River in southern Utah, and water quality issues affecting endangered species in the Provo River–Utah Lake drainage in the northern part of the state. These projects involved collaborative partnerships with numerous local, state, and federal agencies and with the recovery programs in those respective basins. Section 104 funds were also used to develop techniques for quantifying the economic consequences of proposed modifications in state water rights management policy relative to groundwater in the Beryl−Enterprise area in southern Utah.

The project in the Virgin River, entitled "Two−Zone Temperature and Solute Model Testing and Development in the Virgin River", focuses on the development of modeling techniques that provide a detailed understanding of all important heat exchange processes for more accurate predictive capabilities. These models will enable management strategies to be identified that control small temperature fluctuations in order to better protect endangered fish species in the Virgin River.

The Provo River and Utah Lake in central Utah provide critical habitat to the June sucker, an endangered species of fish unique to these water resources. The purpose of the project entitled "Development and Calibration of a Hydrodynamic Model for Utah Lake" is to develop a computer model that will:

Predict water circulation patterns over time

Predict temperature distributions in the lake over time

Predict the free drifting path that June Sucker larvae follow as they flow into the lake through the Provo and Spanish Fork Rivers and tributaries

Determine the influence and effect of key controlling parameters, such as wind speed, air temperature, etc., on the water circulation patterns and temperature distributions.

The project entitled "Economic and Fiscal Impacts of the Groundwater Management Plan in the Beryl−Enterprise Area" described under the Research Project section of this report quantifies the economic impacts of alternative strategies for managing changes in groundwater piezometric levels that have been rapidly falling in the Beryl−Enterprise area due to overdrafting. These alternative strategies reflect potential changes in the administration of groundwater water rights in the State of Utah.

Development and Calibration of a Hydrodynamic Model for Utah Lake

Basic Information

Title:	Development and Calibration of a Hydrodynamic Model for Utah Lake
Project Number:	2007UT80B
Start Date:	3/1/2007
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	UT3
Research Category:	Engineering
Focus Category:	Management and Planning, Models, Water Quality
Descriptors:	None
Principal Investigators:	Robert E. Spall, Barton L. Smith

Publication

Development and Calibration of a Hydrodynamic Model for Utah Lake

Problem

Utah Lake is the largest freshwater lake in the state of Utah and plays a vital role in the region's ecosystem. The lake strongly influences the temperature and moisture content of the air in the region, acts as a storage basin for agricultural irrigation water, provides wetlands that are an important stopover and nesting area for over 200 species of migratory birds, and is used for recreational purposes by those living in Utah Valley. However, the ecology of Utah Lake has transformed over time as a result of a growing human population in the region and the introduction of non-native fish. As a result, some native species are now extinct while the survival of others, like the June Sucker, is now at risk.

Utah Lake has a surface area of approximately 391 square kilometers (151 square miles) and contains about 1073 x 10^6 m^3 (870,000 acre-feet) of water. Despite its large size, however, it is classified as a shallow lake. Its maximum depth is 4.3 meters (14 feet), and its average depth is 2.74 meters (9.6 feet). Shallow lakes such as Utah Lake are typically found in one of two possible, stable ecological states. The first, a clear water state, is characterized by an abundance of aquatic plants along the lakebed and a water condition that allows sunlight to reach the bottom of the lake. The second, a turbid state, is characterized by large amounts of phytoplankton and suspended sediment that prevent the sun's rays from reaching the lakebed. The clear water state is considered to be the pristine state for shallow lakes. While originally in a clear water state, Utah Lake has gradually transitioned to a turbid state.

As a result of this change in the water condition and plant life in Utah Lake, several native fish species have struggled to survive. The June sucker, which once had populations numbering in the millions in the early 1800's, is now on the endangered species list and has a natural population of less than 1000 today. The Bonneville cutthroat trout, the original predator fish in the ecosystem of Utah Lake, and the Utah Lake sculpin, a bottom-dwelling species, both became extinct in the 1930's. The last collected specimens of each were taken in 1932 and 1928, respectively.

In response to the threat of extinction of the June sucker, organizations have been formed to determine ways to improve the ecology of Utah Lake and restore it, if possible, to its pristine, clear-water state. One of these groups, the June Sucker Recovery Implementation Program (JSRIP), combines members of multiple agencies and with a variety of backgrounds into one cohesive group.

Research Objectives

The Utah Lake modeling effort had the following objectives:

- Predict water circulation patterns over time.

- Predict temperature distributions in the lake over time.

- Predict the free drifting path that June Sucker larvae follow as they flow into the lake through the Provo and Spanish Fork Rivers tributaries.

- Determine the influence and effect of key controlling parameters such as wind speed, air temperature, etc., on the water circulation patterns and temperature distributions.

In order to accomplish the above stated objectives and accurately reflect possible variations in physical conditions, different values were used for the relevant forcing functions.

Limitations

It should be noted, however, that while the model does generally predict the circulation patterns and water temperatures over time, it should not be expected to give exact conditions at any given time in the solution interval. Small variations between the model and actual water flow conditions will exist. This is due to the highly nonlinear nature of the Navier-Stokes equations upon which the model is based and the impact of unpredictable extreme natural events such as storms, forest fires, etc. In addition, annual variations in precipitation, regional temperatures, and river flow volume and temperatures will affect the state of Utah Lake.

Instead of making exact predictions of lake conditions at a specific time, the model is useful in generally characterizing the direction and velocity of water currents in Utah Lake. It also provides a way to predict general temperature distributions over time. In addition, the model identifies and determines the relative importance and influence of the external forcing functions. Finally, it is useful in determining the general impact of changes in other key parameters on the circulation patterns, temperature distributions, and larvae drift paths.

Methodology

Computational fluid dynamics (CFD) is the branch of fluid mechanics dealing with the simulation of physical fluid flows through the use of numerical methods and computational algorithms. These methods are based on the governing equations of fluid mechanics, and are used to obtain detailed results about the flow field, such as velocities, pressures, and temperatures, etc. A CFD simulation requires that the physical geometry, fluid properties, initial conditions, and forcing boundary conditions for the scenario be defined. A mesh consisting of individual cells is then generated. The advent of computers and the increasing availability of powerful processors has allowed for extensive use of CFD modeling for many industrial and commercial purposes. In recent years, detailed codes have been written specifically for CFD simulations of lakes and other large bodies of water.

CFD models of lakes and other naturally occurring bodies of water require an additional degree of complexity beyond a normal CFD simulation, however, in order to account for all of the natural processes that drive the system. Both the fundamental simulation codes and the forcing functions must be adapted to handle variations over time in air temperature, solar radiation, wind speed, precipitation, cloud cover, and other vital external functions. Appropriate methods for calculating heat transfer through the water's surface, evaporation rates, effects of Coriolis forces, and the amount of solar radiation incident upon the lake as a function of time of year and position on the earth's surface must also be incorporated. In addition, variations in water composition (i.e. salinity, total dissolved solids (TDS), density, etc.) and the possibility of a stratified system must be accounted for. All of these complexities introduce approximations and consequent sources of error into the CFD codes.

Development of the model for Utah Lake required the following steps:

- Generation of a mesh that accurately depicted the physical boundaries of Utah Lake. This mesh was developed from the topography shown in Figure 1 below. The resulting discretized lake is shown in Figure 2.

- Gathering of accurate data on the surface water boundary conditions as a function of time, including river locations, inflow and outflow rates, and water temperature values.

- Collection of accurate meteorological forcing data as a function of time, including air temperature, atmospheric pressure, cloud cover, precipitation, relative humidity, solar radiation, and wind speed and direction.

- Generation of input files formatted to CWR-ELCOM's specifications.

- Execution of the code to run the simulations.

    - Post-processing and analysis of the results, including model validation.

Principal Findings

The approximate locations of the sensors were marked on a copy of the Fish-n-Map Co.'s Utah Lake map by Brandon Wilson, one of the Utah State University students charged with maintaining the sensor chains during the summer of 2007. The image of this map was digitized using the *XYit* software to extract the coordinates for each sensor chain. Because of the interpolations used in creating the mesh, sensor chains located close to shore would appear to be in dry cells for large horizontal spacing. The locations of the sensor chains in a 500-meter (1640-foot) mesh are shown in Figure 3.

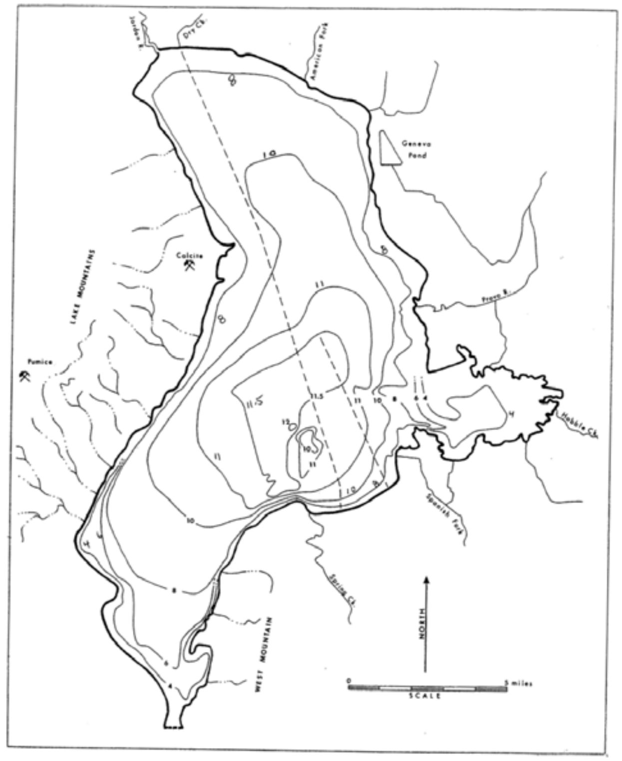

Figure 1. Utah Lake Map from Heckmann (1981)

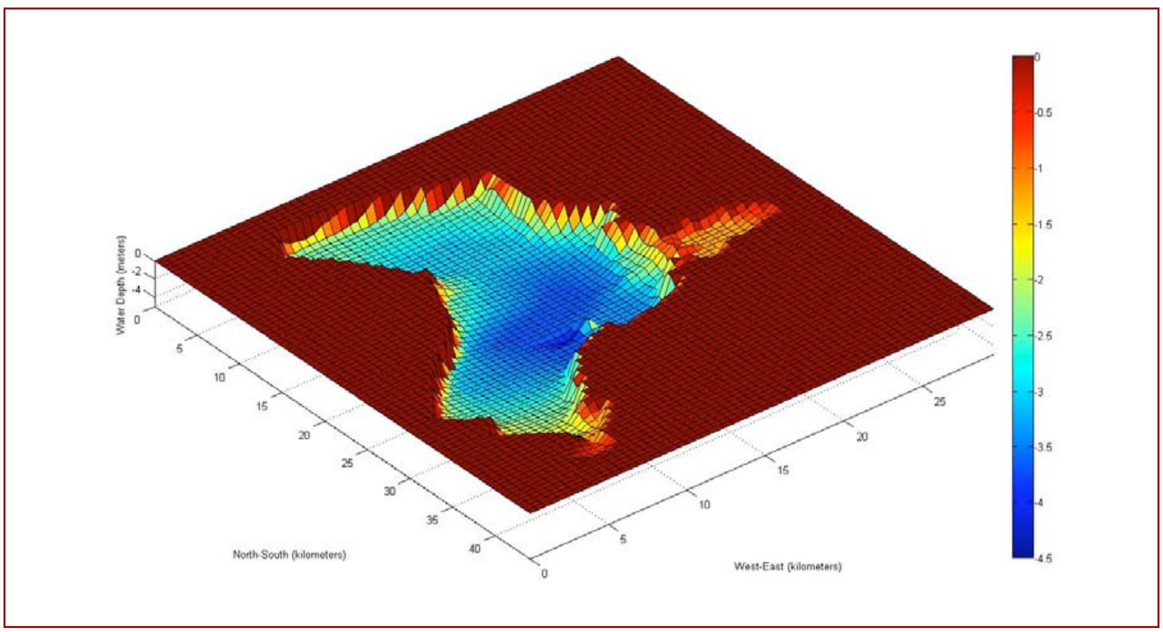

Figure 2. Utah Lake 500-meter grid.

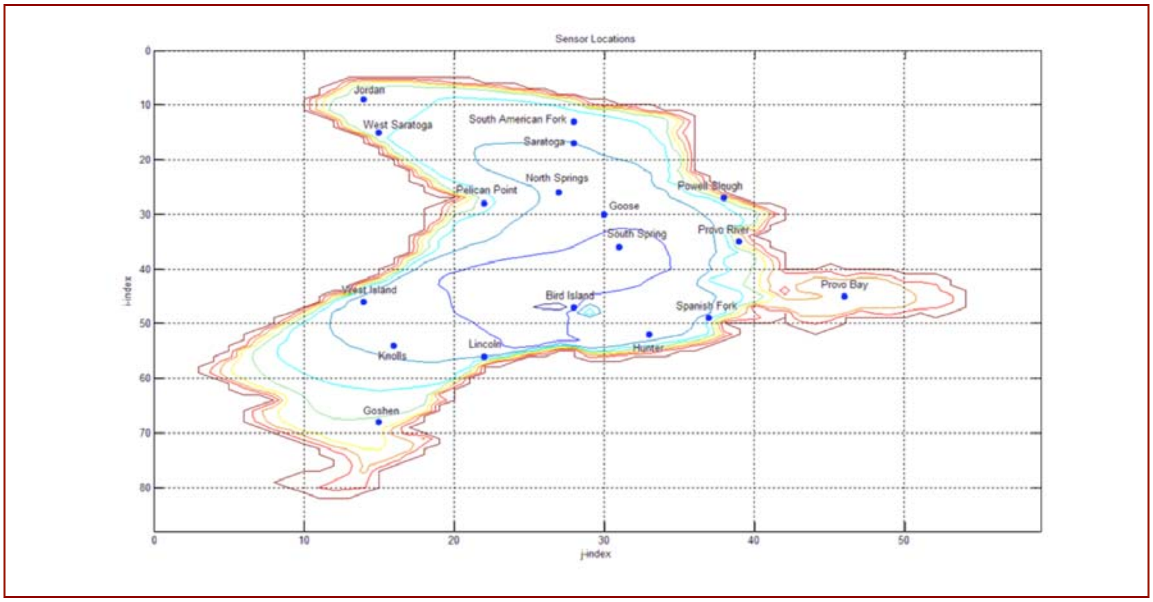

Figure 3. Location of temperature sensors.

Actual vs. Simulated Temperatures

Once the simulations were completed, the numerical results were compared to the actual temperature data recorded by the sensor chains to determine the approximate accuracy of the model. As mentioned above, unexpected natural phenomenon preclude the model from being able to predict the exact temperature and flow conditions at any point in the simulation time, but instead give average values for each. Figures 4-6 depict selected plots of the actual and simulation temperature values at three of the sensor chain locations. The simulation manages to approximate the actual temperature values to within a few degrees at these three locations over the range of the simulated time. Close examination of the plots, however, reveals that the simulation slightly under predicts the temperatures for the year 2007.

Analysis of the sensor chain data revealed that several of the locations had unrealistic temperature values over a portion of the time in which they were recording measurements. For example, Figure 6 depicted the actual and simulation temperatures at the Saratoga sensor chain location after day 165 (June 14th). However, the complete data set from the sensor chain is shown in Figure 7, where a large amount of invalid experimental data is found at the beginning of the data set.

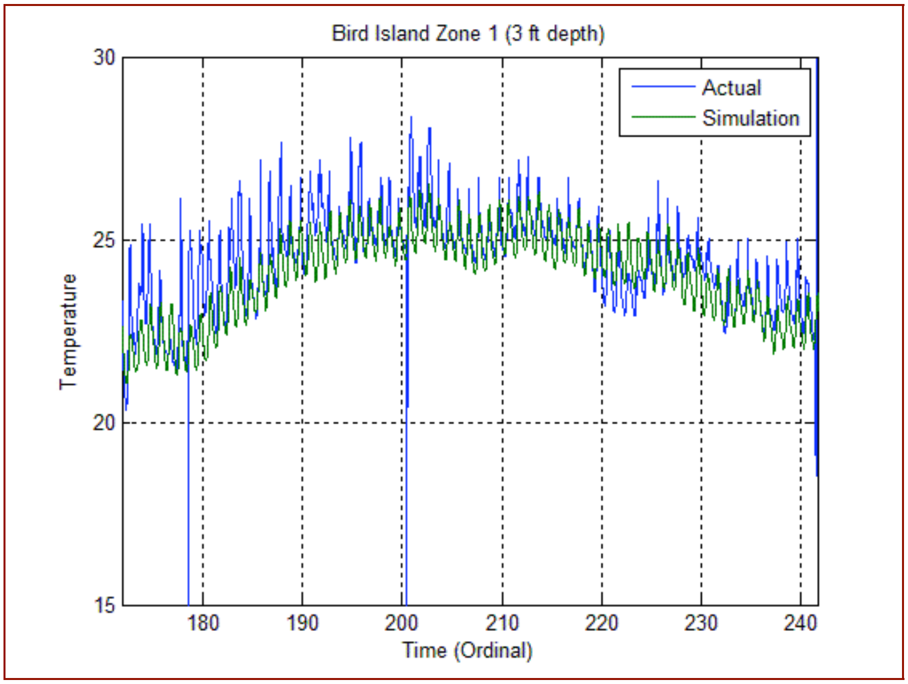

Figure 4. Actual vs. simulation temperatures at Bird Island sensor location.

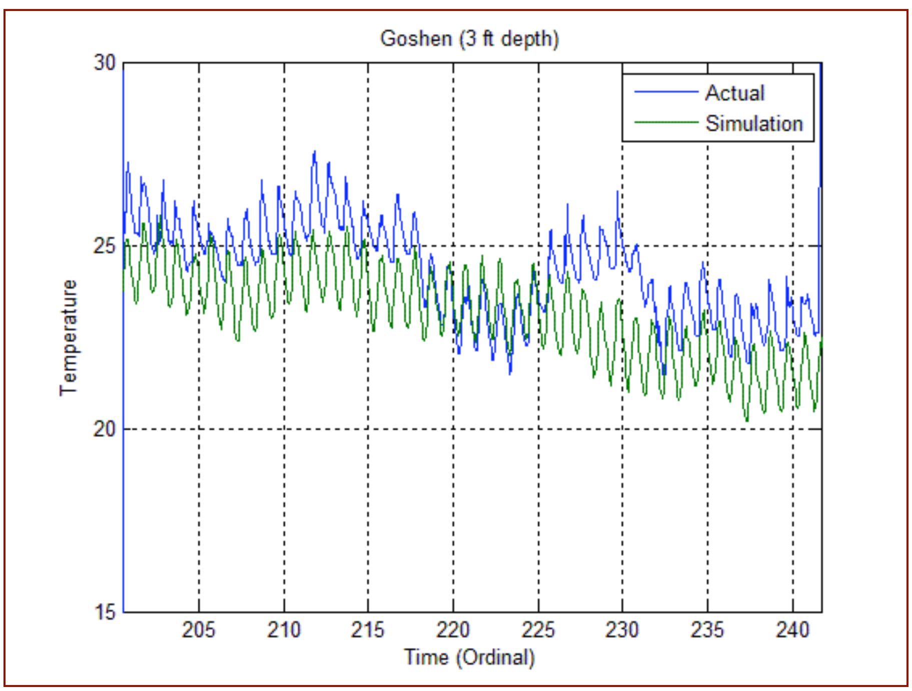

Figure 5. Actual vs. simulation temperatures at Goshen sensor location.

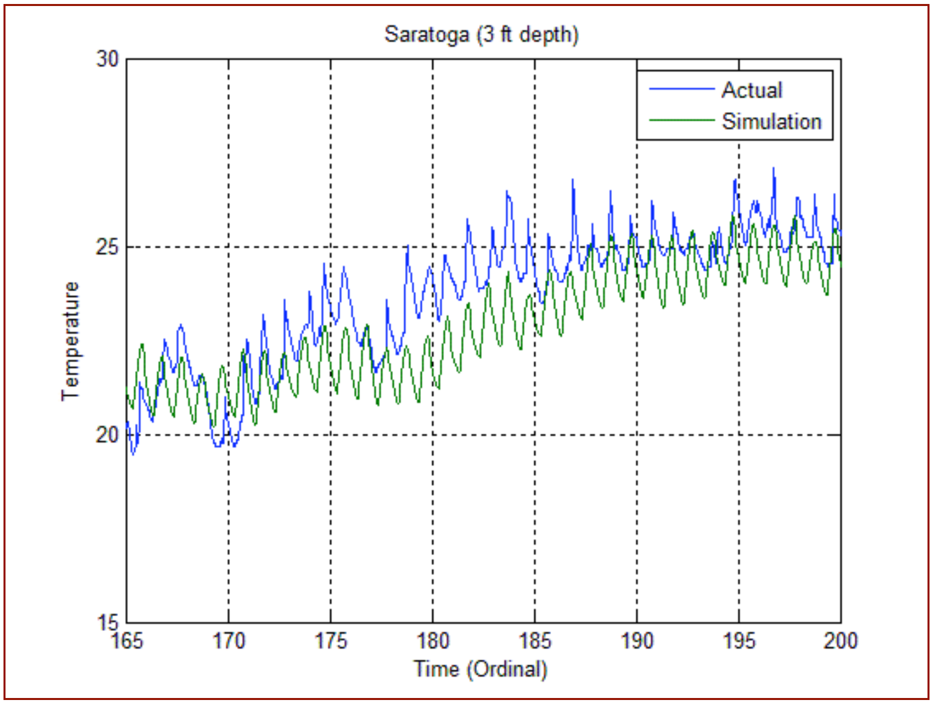

Figure 6. Actual vs. simulation temperatures at Saratoga sensor location.

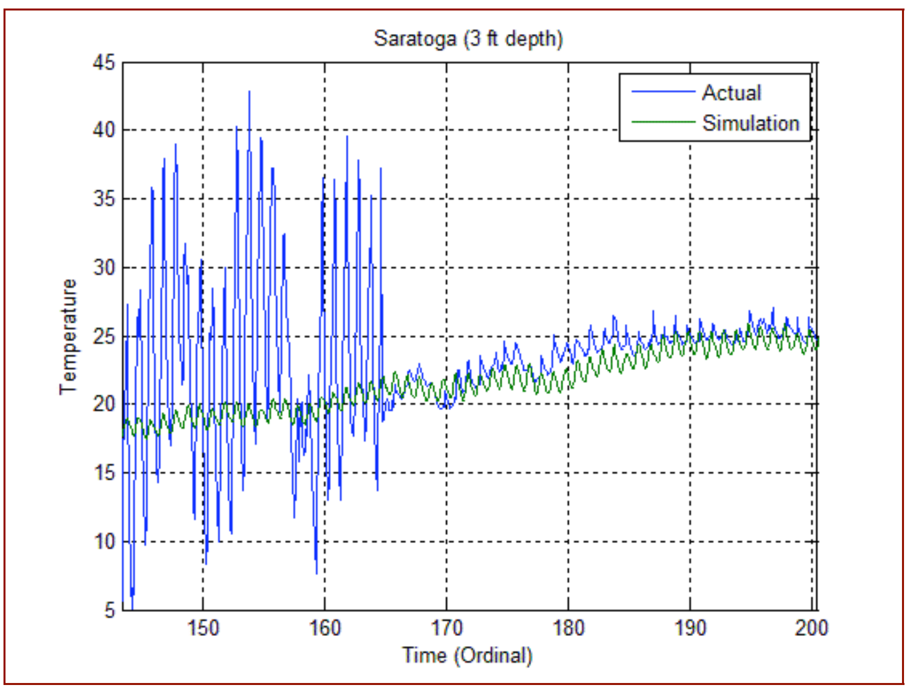

Figure 7. Complete data set for temperature measurements at Saratoga location.

The Utah Lake model has several sources by which error was introduced into the model. However, it is much easier to identify the sources of error than to quantify the magnitude of error in the model due to each source; the majority of the error was introduced from data sources with an unreported amount of error in the measurement results. The major sources of error and the anticipated impact of these errors can be discussed qualitatively, however.

One source that is inherent in every simulation comes because of the assumptions and numerical methods used to translate the governing equations into the computational algorithms that compose CWR-ELCOM. However, usage of CWR-ELCOM in other applications has shown that the magnitude of the errors thus introduced should be fairly small when compared to other possible sources.

The largest sources of error are the uncertainties in the data used as inputs for every simulation. While the simulations assumed that the forcing functions were evenly applied across the surface of the lake, the various sensors used to generate the data were actually located at ground stations around the lake. Because of the influence the lake exerts on the air above it, a certain amount of error was introduced through the use of this data.

Furthermore, the individual measurements themselves had a certain amount of error inherent because of equipment sensitivity and calibration. However, due to the averaging process used to produce the final data sets, the effects of the error in each measurement mostly canceled each other out and were small when compared to the errors due to strong natural phenomena.

Other data sets that served as inputs to the Utah Lake model were derived from mathematical models of natural phenomena. Specifically, cloud cover was calculated from the interpolated relative humidity values using a rough model found in the literature, and the solar radiation values were then calculated using the cloud cover values by a model that had been proposed by Martin and McCutcheon. Because of their dependence on the accuracy of the relative humidity values and the models upon which they were based, additional error was introduced into the model through these data sets.

As a result of these possible sources of error and the highly nonlinear nature of the governing differential equations, the simulations cannot be expected to agree exactly with actual measurements taken from the lake itself. Nevertheless, we consider the performance of the model in predicting temperature levels within Utah Lake to be excellent. Consequently, the model should be a valuable tool in further water quality analysis of Utah Lake.

Economic and Fiscal Impacts of the Groundwater Management Plan in the Beryl−Enterprise Area

Basic Information

Title:	Economic and Fiscal Impacts of the Groundwater Management Plan in the Beryl−Enterprise Area
Project Number:	2007UT83B
Start Date:	3/1/2007
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	UT2
Research Category:	Social Sciences
Focus Category:	Water Supply, Water Quantity, Economics
Descriptors:	
Principal Investigators:	John E. Keith

Publication

ECONOMIC AND FISCAL IMPACTS OF THE GROUNDWATER MANAGEMENT PLAN IN THE BERYL-ENTERPRISE AREA

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Introduction: Asset values

Most assets generate a return. For example, if you put $1,000 in the bank in a 5% CD, the return is compounded over time. That is, every year that you leave the principle ($1,000) plus its earned interest in the account, you earn another 5% on the total for that year. The value of that $1,000 at the end of 20 years is $2,653 ($1,000 X 1.05 X 1.05 X 1.05 X…for 20 years). You could also ask what you would need to invest today at 5% to have $2,653 at the end of 20 years. That is a concept called "present value." The present value of $2,653 twenty years from now is $1,000 today. This is the same way that any asset value works. Note also that if we deposited $1,000 per year for each of the 20 years, the total value at the end of 20 years would be $33,066. That's $1,000 times 1.05 twenty times plus $1,000 times 1.05 nineteen times plus…and so on. What is the present value of that stream? It is $\$33{,}066/(1.05)^{20}$ or $12,462 which is called the present worth (value) of $1,000 per period for twenty years at 5%. How does this relate to land value?

The value of land is the present worth of the stream of net benefits that land will bring over the lifetime of the land. For example, if you wanted to find out the present value of an acre of ground that would give a net profit of $170 every year for the next 50 years, that value would be $3,103. That is, I could deposit $3,103 in the bank at 5% and withdraw $170 per year for 50 years. If I were faced with the purchase of that acre of ground, knowing that it would generate $170 per year for 50 years, and the interest rate I could earn was 5%, what would I pay for the acre? Not more than $3,103.

Land Value in the Beryl-Enterprise Area

To look at the current value of agricultural land, we can use the present value of the return streams. For irrigated alfalfa, the Utah State Extension Service estimates a net return in the Beryl-Enterprise area of about $242 per acre without pumping costs using 2006 prices and costs. Pumping costs are calculated using data from the USU Extension Service. At current aquifer levels, pumping costs are estimated at about $70 per acre. Thus, current net profit is about $170 per acre for alfalfa. In addition, it is estimated that each additional foot of drawdown of the aquifer will add $0.32 per acre in pumping cost. Current data suggest that the peisiometric head is falling at an average of about 1.12 feet per year, particularly in the area in which heavy irrigation is taking place. Thus, pumping costs will increase through time as the peisometric head is reduced by continued pumping. If the present value of profits per acre of alfalfa net of increasing pumping costs over time is calculated, it equals about $3,000 over 50 years and $3,250 in perpetuity. With the current cropping pattern, the present value of profits less increased pumping costs is somewhat lower (approximately $2,800 over 50 years and $3,000 in perpetuity). If one uses the current price of alfalfa ($150 per ton on average according to the Utah State Department of Agriculture website), and assuming the costs of production have increased about 10% to $273 per acre, the net profit has increased to $552 without pumping costs. If we assume that energy costs have or will rise approximately 10%, the cost of pumping increases to $77 per acre yielding a net return of $475 per acre. Pumping costs will increase at $0.35 per one foot of increased pumping depth, or approximately $0.39 per acre per year. The resulting present value of farm profits per acre would be approximately $8,540 at 50 years, and $9,300 in perpetuity. The latter two values appear to be approximately double the current market, although some sales in that range have occurred in the past year. It is more likely that costs of production of irrigated crops will increase proportionately with the increases in prices of crops. Thus, profitability per acre of irrigated crops will probably not increase the full $475 per acre, but rather significantly less than that. At this time, there are no data on which to calculate the long term increase in profitability per acre.

Table 1. Crop water use and returns

Crop	Consumptive Water Use in acre feet per acre	Water Duty (acre feet per acre)	Gross Sales/acre	% area	Proportional Gross Sales/acre for current crop patterns	Net return per acre without pumping costs[1]	Net return per acre with pumping costs
Alfalfa	2.49	3.4	$490	86	$421	$242	$170
Alfalfa (2007)	2.49	3.4	$825	86	$710	$272	$438
Grain (Barley)	1.66	2.27	$202	08	$16	-$68	-$115
Corn	1.38	1.89	$625	02	$13	$125	$95
Grass Hay	2.25	3.01	$233	04	$9.50	-$50	-$113
Average current							$134
Potatoes[2]	1.41	1.93	$1,615			$138	$98
Canola[3]	1.30	1.78	$300			$36	$1

The mean value of irrigated land in the Beryl-Enterprise area (according to the Farm Credit Services, the Farm Bureau and banks involved in farm credit) ranges from $4,000 to $4,500 per acre. There may have been sales for more – or less – than this amount, but the banks and other lending agencies are pretty consistent in their evaluation of land value. Any difference between the present value of the return stream and the sale price of land is likely due to expected

[1] Taken from the most recent USU Extension Service crop budgets for Iron County unless otherwise noted.

[2] Taken from University of Idaho Extension Service crop budgets for Southeastern Idaho. How accurate this net return is for the Beryl-Enterprise region is unknown.

[3] Taken from USU Extension Service specialty crop budgets for Northern Utah. How accurate this net return is for the Beryl-Enterprise region is unknown.

increases in profitability of crops, particularly corn and alfalfa, and the potential for developing land for other uses (such as ranchettes). Nevertheless, the calculated values are reasonably consistent with the present value calculations. According to those same lending agencies, dry land (without irrigation water) value ranges between $250 and $500 per acre.
However, most of these sales have been to consolidate unirrigated "corners" of property, rather that stand-alone dry land. Most lenders suggest that land entirely without water has no value in the region.

Land Value and Irrigation

If irrigation water is not available to a farmer the net loss per acre ranges between $4,000 and $4,500 per acre. We can calculate the present value of that loss as indicated in Table 2 below. The figures in the PV loss columns indicate the approximate reduction in the land value if pumping is delayed by the number of years in the "t" years in the future column. Quite clearly, the longer the period before a reduction in withdrawals, the less the present value of that cost (loss in value) to irrigators.

Table 2. Present values of the net loss of $4,500 per acre

	Present Value of $4,500 at 5%	Present Value of $4,500 at 10%
1	4285.714	4090.909
2	4081.633	3719.008
3	3887.269	3380.917
4	3702.161	3073.561
5	3525.868	2794.146
6	3357.969	2540.133
7	3198.066	2309.212
8	3045.777	2099.283
9	2900.74	1908.439
10	2762.61	1734.945
11	2631.057	1577.223
12	2505.768	1433.839
13	2386.446	1303.49
14	2272.806	1184.991
15	2164.577	1077.264
16	2061.502	979.3311
17	1963.335	890.301
18	1869.843	809.3646
19	1780.803	735.786
20	1696.003	668.8963
21	1615.241	608.0876
22	1538.324	552.8069
23	1465.071	502.5517
24	1395.306	456.8652
25	1328.862	415.332

Table 2 (Cont'd)

26	1265.583	377.5745
27	1205.317	343.2496
28	1147.921	312.0451
29	1093.258	283.6773
30	1041.199	257.8885
31	991.6176	234.4441
32	944.3977	213.131
33	899.4264	193.7554
34	856.5966	176.1413
35	815.8063	160.1285
36	776.9584	145.5713
37	739.9603	132.3376
38	704.7241	120.3069
39	671.1658	109.3699
40	639.2056	99.42718
41	608.7672	90.38834
42	579.7783	82.17122
43	552.1698	74.70111
44	525.876	67.9101
45	500.8343	61.73645
46	476.985	56.12405
47	454.2715	51.02186
48	432.6395	46.38351
49	412.0376	42.16683
50	392.4168	38.33348
51	373.7303	34.84862
52	355.9336	31.68056
53	338.9844	28.80051
54	322.8422	26.18228
55	307.4688	23.80208
56	292.8274	21.63825
57	278.8833	19.67114
58	265.6031	17.88285
59	252.9553	16.25714
60	240.9099	14.77922
61	229.438	13.43565
62	218.5123	12.21423
63	208.107	11.10384
64	198.1971	10.0944
65	188.7592	9.176731
66	179.7706	8.342482
67	171.2101	7.584075
68	163.0573	6.894613

Table 2 (Cont'd)

69	155.2926	6.26783
70	147.8978	5.698028
71	140.855	5.180025
72	134.1476	4.709114
73	127.7596	4.281013
74	121.6758	3.89183
75	115.8818	3.538027
100	110.3636	0.326546

As can be seen, the present value of the loss of water beyond 70 years is small, and beyond100 years is approaching insignificant.

Alternatives to Dry Land

What alternatives could be considered in the face of the reduced pumping? For example, if irrigation water is limited to 34,000 acre feet per year, what is the best solution for the region and for the farmer? We can examine this question using a "what if" analysis (linear programming model) that maximizes the net return to the land and water under a constrained situation (using the USU crop budget data for 2006). There are three possible alternatives. The first is to examine each individual farmer's best choice under limited water availability. The second is to look at only a water constraint, which will maximize the net returns to the land and water in the region, but not necessarily use all the land (some land would be dewatered). The third is to impose the water constraint and a land constraint that forces all the existing irrigated land into production (no land is dewatered).

Results from the linear programming model for the first alternative, using the various net returns (including pumping costs) based on the 2006 USU Extension budgets suggest that farmers who have sufficient water (that is, with senior priority dates) to irrigate all their land in alfalfa would continue to do so, while farmers with junior priority dates would have to dewater their land. Note that this model has ignored any rotation constraints, so that grain, grass hay, and canola are not in the cropping mix. For farmers with a mix of senior and junior water rights, the solutions are not so clear. Depending on the proportion of senior rights a farmer holds, he may irrigate alfalfa on a portion of his land and dewater the rest, or he might use his water to grow the best alternative crop (potatoes or corn) on all of his land, or possible mix the alternative crops. Some examples are presented below from the farmer-based linear programming model.
If the farmer had 500 acres and 1250 acre feet of water rights (sufficient to grow alfalfa on all 500 acres), he would do so. However, if his water rights consisted of 1000 acre feet of senior rights and 250 acre feet of junior rights, the model solution suggest that he would grow 273 acres of alfalfa and 227 acres of potatoes (given that potatoes are the next most profitable crop and use about as much water as corn). The model results were quite sensitive to the combination of profitability and water use. For example, if potatoes were not considered as an available alternative, the farmer would grow all the alfalfa he could (402 acres). If potatoes were about $1.50 less profitable per acre, the same result is generated by the model (or if corn were about

$10 more profitable per acre, corn would be the alternative crop chosen). Table 3 indicates the farmers optimal cropping patterns for various levels of senior water rights.

Table 3. Cropping Patterns with Varying Senior Rights

Senior rights	Alfalfa	Potatoes	Corn
1250	500	0	0
1000	273	227	0
750	41	459	0
720	0	496	0
500	0	355	0
350	0	249	0

Table 3 indicates that as water becomes more scarce, the farmer switches from alfalfa to an alfalfa/potato rotation, and then to strictly potatoes. These solutions rest on the profitability of potatoes per acre foot of water compared to the other alternative crops (approximately $67 per acre foot compared to corn's $61.50 per acre foot) and the amount of land that can be grown in each crop given the water availability.

If we look at the net profit to the basin as a whole, using the safe yield (34,000 acre feet) as the water constraint, the model suggests that about 24,000 acres of potatoes would be grown. Since alfalfa is only slightly more profitable than potatoes per acre foot ($68 per acre foot), as the water becomes more scarce, it pays (to the region as a whole) to shift to potatoes, but growing alfalfa on reduced numbers of acres is more profitable than mixing alfalfa and corn. Again, using somewhat different net returns per acre could change that solution.

If we impose a constraint that no land will be dewatered, the solution for the region changes fairly dramatically. The model indicates that a combination of corn (16,000 acres) and canola (8,900 acres) would be grown. This solution is driven by minimizing the amount of loss related to using more acres than necessary. It selects the "least" costly crop to grow on those excess acres. While the solution may be unrealistic, it suggests that a political solution (in the form of assuring that no farmer has to idle land) may be counter-productive.

Taken together, these solutions suggest that if farmers take their individual actions, the region will be less well off than if there is a cooperative solution. An alternative way of expressing this fact is to suggest that if farmers are allowed to freely trade their water rights, the result will be that alfalfa will be replaced by potatoes in the region, since the model suggests that there are gains to shifting cropping patterns, and the losers (dewatered land) could buy out senior water rights to grow potatoes over on some portion of their land. The senior water rights holders would be compensated for their losses as the production shifts.

If we look at the impact of cropping changes on the value of land, the present value of the net returns per acre to potatoes ($97) is about $1,770. That is a loss of between $1,380 and $1,730 per acre. There would also be the loss of around $3,000 per acre for the fallowed land (about 1,500 acres). Once again, the longer the delay in reducing pumping to safe yield, the smaller will be the effect on land value today.

Community Economic Impacts

Now look at community impacts. The analysis could include just Iron County, or Iron County and Washington County, since most of the purchases of inputs and by households come from those counties. To estimate the maximum local effect, the Iron and Washington County model was constructed.. In order to do that, it is necessary to make some assumptions about the rate at which pumping will be reduced. Suppose that 5% of the 32,000 acre feet of pumping are reduced per year, resulting in the loss of 1,600 acre feet, or approximately 500 acres. Using the 2006 USU Extension data, that would mean a reduction in gross value of $210,700 in hay sales, $8,080 in grain sales, $6,250 in corn sales, and $4,660 in grass hay sales per year (increasing every year by that amount. The entire 32,000 acre feet reduction would mean a loss of 10,000 acres with a total of $4,214,000 in hay sales, $161,600 in grain sales, $125,000 in corn sales, and $93,200 in grass hay sales.

For the community, loss of jobs, gross sales, and household income from these reductions can be computed using an input-output model (IMPLAN, as discussed earlier). Assume that 90% of the hay grown in the Beryl Enterprise region is exported, 70% of the grain is exported, 70% of the corn silage is exported and 50% of the grass hay is exported. That yields a loss in exported value as follows:

Crop	Annual loss	Total loss
Alfalfa	$189,630	$3,792,600
Grain	$ 5,656	$ 113,120
Corn	$ 4,375	$ 87,500
Grass Hay	$ 2,330	$ 46,600

The associated direct losses in jobs, household income and regional sales would be:

	Jobs	Household income	RGO
Annual	0.5	$ 46,133	$ 194,812
Total	10	$922,656	$3,896,247

It is likely that this entire impact would be felt in the Beryl-Enterprise area.
As a result of these direct losses, the annual and total loss in jobs, household income and total regional gross output (RGO) or total sales of goods and services within the two-county region would be:

	Jobs	Household income	RGO	State and local taxes*
Annual	1.5	$ 67,410	$ 266,342	$ 11,926
Total	29.6	$1,348,198	$5,326,837	$238,512
*exclusive of school taxes				

These losses are a small portion of the total jobs, income, and RGO of the two-county region (less that 0.2% in all three measures), but, as indicated above, most of the impact will be felt in the Beryl Enterprise area and will likely be significant to that community.
For Iron County alone, the results are as follows:

	Jobs	Household income	RGO	State and local taxes*
Annual	1	$ 60,498	$ 250,739	$ 11,149
Total	19.2	$1,209,963	$5,014,772	$222,973
*exclusive of school taxes				

There is not a significant difference between the two regional alternatives, with the exception of the "jobs" category. That difference arises from the number of direct jobs lost between the two regional definitions (5.5 for Iron County and 9.9 for the two-county region).

If, on the other hand, we use the current price data and consider that only alfalfa production would be lost (likely an overestimate, since water would probably be transferred to the higher valued crop), that would mean a reduction in gross sales value of $536,250 in annual hay sales. The entire 32,000 acre feet reduction would mean a loss of 12,500 acres with a total of $10,312,500 in hay sales. For the community, loss of jobs, gross sales, and household income from these reductions are:

	Jobs	Household income	RGO
Annual	1.2	$ 74,500	$ 600,000
Total	24.7	$1,490,000	$12,000,000

It is likely that this entire impact would be felt in the Beryl-Enterprise area.

As a result of these direct losses, the annual and total loss in jobs, household income and total regional gross output (RGO) or total sales of goods and services within the two-county region would be:

	Jobs	Household income	RGO	State and local taxes*
Annual	2.0	$ 118,320	$ 745,030	$ 25,125
Total	39.2	$2,366,350	$14,900,610	$502,470
*exclusive of school taxes				

These losses are a small portion of the total jobs, income, and RGO of the two-county region (less than 0.5% in all three measures), but, as indicated above, most of the impact will be felt in the Beryl Enterprise area and will likely be significant to that community.

Several community members have suggested that the employment changes are much too low. As an example, one farmer who has approximately 8 sprinkler sets (about 1,000 acres), has approximately 3.5 full time employees, yielding about 0.4375 employees per sprinkler set. For the loss of 12,500 acres, that would mean approximately 45 jobs lost. Using the jobs lost figure as the basis for the impact analysis, the following results were obtained:

	Jobs	Household income	RGO
Annual	2.3	$ 132,750	$ 834,000
Total	45.0	$2,655,000	$16,680,000

It is likely that this entire impact would be felt in the Beryl-Enterprise area.

As a result of these direct losses, the annual and total loss in jobs, household income and total regional gross output (RGO) or total sales of goods and services within the two-county region would be:

	Jobs	Household income	RGO	State and local taxes*
Annual	5.3	$ 210,900	$ 1,092,550	$ 44,785
Total	105.5	$4,218,000	$21,851,000	$895,706
*exclusive of school taxes				

Again, these values are significant for the local community, but not a significant impact on the two-county region.

If we assume that about 25% of the alfalfa produced is cubed and those cubes exported, that means that approximately 17,200 tons of cubed hay would be exported at approximately $180 per ton, or approximately $3,000,000 of reduced exports from cubed hay. The remaining 51,562 tons of exported hay would lost, or approximately $7,750,000. Using these figures, the community losses would be as follows:

	Jobs	Household income	RGO
Annual	2.0	$ 89,710	$ 630,000
Total	40.7	$1,794,200	$12,600,000

Again, it is likely that this entire impact would be felt in the Beryl-Enterprise area.
As a result of these direct losses, the annual and total loss in jobs, household income and total regional gross output (RGO) or total sales of goods and services within the two-county region would be:

	Jobs	Household income	RGO	State and local taxes*
Annual	4.8	$ 161,270	$ 869,320	$ 30,089
Total	96.4	$3,224,350	$17,386,400	$601,780

If we look at the alternatives suggested by the models – that potatoes will be grown instead of alfalfa – the net export (at 90%) would be $1,453.50 per acre over 24,000 acres, or a total of $34,872,000. The IMPLAN model predicts that for the two-county region there would be a net gain of about 15 jobs, household income of $886,000, total value added of $1,913.300 , and total RGO of $34,194,500. The large change in RGO relative to the other changes is a result of the fact that many of the inputs for potato production would be purchased from outside the local area (according to the data in the IMPLAN model). Nevertheless, the shift would offset the losses due to reduced alfalfa exportation. The results for Iron County alone are slightly smaller, as expected.

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Two−Zone Temperature and Solute Model Testing and Development in the Virgin River

Basic Information

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Two-Zone Temperature and Solute Model Testing and Development in the Virgin River

Abstract

Water shortages and drought resulting in low stream flows are commonplace in Utah. Although water quantity tends to be the focus of efforts to cope with low flows, the effects on instream temperatures are additionally a high profile aspect of water quantity management in this arid region. Water temperature is important in an aquatic system because of its integral relationship with chemical and biological reaction rates. Additionally, temperature-related water quality impairments are ninth on the U.S. Environmental Protection Agency's Top 100 Impairments list. This includes many rivers in Utah that support species, including endangered fish species that are sensitive to small temperature fluctuations. To enable management strategies that control small temperature fluctuations, modeling techniques that provide a detailed understanding of all important heat exchange processes are necessary for more accurate predictive capabilities. Temperature models that are currently available to assist in heat load allocations are limited in that they do not represent all of the important heat fluxes (e.g., hyporheic and dead zone processes).

This project consisted of a data-centric approach to collecting information about energy and mass fluxes in streams to be used in temperature and solute model parameter estimation for high-gradient watersheds. Past efforts for modeling river hyporheic and dead zone processes have used a lumped or one-zone approach where the total of the surface (dead zones) and subsurface (hyporheic zone) storage was referred to as transient storage. A two-zone temperature and solute model was formulated and tested at Utah State University that includes hyporheic and dead zone effects on the transport and fate of contaminants through exchange and biochemical transformations. The two-zone model, coupled with the observations of temperatures and solute concentrations in different zones, allows for separation of transient storage into surface and subsurface storage zones. The results of two-zone model calibration in a desert river for solute fate and transport have proven to be more representative of the surface storage zone than the lumped, one-zone approach. Similarly, the two-zone model calibration for temperatures in each zone resulted in more accurate temperature estimates in each zone and, therefore, in the main channel. There is still, however, a need to predict how these storage zones and the resulting instream temperatures change under different flow regimes. This project provided for: 1) data collection that will be used in the testing and possible enhancement of the two-zone temperature and solute stream model, and; 2) future testing of parameter transferability between different flow regimes in a portion of the Virgin River, Utah.

Statement of Critical State Water Problem

Water shortages and drought resulting in low stream flows are commonplace in Utah. In Washington County, rapid population increases and the associated water requirements have created consistent water shortages resulting in a number of water development projects (Sand Hollow Reservoir (2003) and the proposed Lake Powell pipeline). Although water quantity tends to be the focus of efforts to cope with low flows, the effects on instream temperatures are additionally a high profile aspect of water quantity management in this arid region due to two endangered species that are unique to the Virgin River (Virgin River Chub (*Gila seminuda*) and woundfin (*Plagopterus argentissimus*)). Temperature is important in an aquatic system because of its integral relationship with chemical and biological reaction rates. Under the Clean Water Act, states must establish water quality standards for temperature that meet the needs of sensitive species. Once these standards are set, states must understand when these limiting conditions occur, what caused the impairment, and which management options will remedy the impairment. Temperature-related water quality impairments are currently ninth on the U.S. Environmental Protection Agency's (EPA's) Top 100 Impairments list (EPA 2004).

Temperature models available to assist in heat load allocations have limitations in the types of heat fluxes included. Sources and sinks of heat may be important in high-gradient streams that are typically not considered include bed conduction, hyporheic processes, dead zone processes, riparian and topographic shading, and shortwave solar radiation fate in the water column and bed substrate. Modeling each of these heat fluxes requires a mathematical representation of how heat or mass is exchanged between zones. Past efforts to model storage processes in rivers have implemented a transient storage concept. Transient storage lumps hyporheic storage, dead zones, and other slow moving water relative to the main channel flow (Bencala and Walters 1983). Transient storage has commonly been added to a convection-dispersion model of one-dimensional solute transport as a first order mass transfer between the main channel and the storage (Bencala and Walters 1983; Runkel 1998). Lumped models require estimation of parameters corresponding to the extent of the storage and exchange rates that are typically estimated from a solute tracer experiment. This stream-tracer approach to modeling solute transport lumps the surface and subsurface storage into one-zone and therefore, is considered a one-zone stream solute model.

One-zone modeling may not fully represent characteristics of surface or subsurface processes (Harvey and Wagner 2000; Runkel and McKnight 2003), rather they represent an average of all the processes. As pointed out by Packman and Bencala (2000), quantification of surface-subsurface hydrologic interactions is critical in understanding exchange of constituents between the surface and subsurface zones. Additionally, Runkel and McKnight (2003) stress the importance of determining the volume and rate of exchange for instream storage and hyporheic storage with the main channel separately. They also mention that the formulation of models with multiple storage zones may be straightforward, but the development of practical field methods to parameterize such models may not be.

Recent research completed at Utah State University (USU) addressed the needs associated with distinguishing the surface and subsurface storage zones' processes, resulting in a two-zone temperature and solute model that incorporated *in-situ* solute and temperature measurements for model population and calibration (Neilson 2006). This model contains terms associated with surface heat fluxes in the main channel and dead zones (including shortwave radiation, atmospheric longwave radiation, back radiation (water longwave radiation), conduction, and evaporation), heat and mass exchange between the dead zones and the main channel, heat and mass exchange between the hyporheic storage and the main channel, heat exchange due to bed and deeper ground conduction, and heat exchange with the sediment due to solar radiation penetration. Therefore, the model includes parameters related to volumes of the surface and subsurface zones, exchange of mass and heat into the surface and subsurface zones, and shortwave radiation extinction. Heat and mass transfer between the main channel and the storage zones are represented by first-order exchange. Bed and ground conduction are approximated by the thermal properties of the sediments, the depth of the sediments, and a temperature gradient. Solar radiation behavior in the water column and penetration to the bed is approximated by measuring shortwave albedo off of the water surface and light penetration through the water column to the sediments. Extinction coefficients are then calculated from shortwave radiation profiles according to the Beer-Lambert law.

Many types of data need to be collected to characterize the fate and transport of heat and mass in rivers. For the purposes of two-zone temperature and solute modeling, certain types of data provide information regarding main channel, surface, and subsurface storage interactions. These data include: temperatures in the main channel flow, dead zones, and sediments; shortwave solar radiation entering the water body, being reflected off the water surface, and entering the substrate of the bed; an understanding of the effects of riparian and topographic shading on solar radiation reaching the water surface; tracer solute behavior in the main channel and dead zones; and additional information necessary for modeling temperatures including headwater temperatures and flows, lateral surface inflow rates and temperatures, and the appropriate weather data. Each data type mentioned provides either a direct or indirect measure of a mass or heat transfer process occurring in the stream. For example, solar radiation measurements using the albedometer provide a direct estimate of the amount of incoming shortwave radiation, radiation reflected off the water surface, and the attenuation of the radiation through the water column. The processes associated with the hyporheic and dead zone exchange, however, are more complex and cannot be measured directly. Therefore, combinations of solute concentrations and temperatures in each zone provide information about the extent and rate of exchange in both the surface and subsurface storage.

Statement of Benefits

More accurate stream temperature predictions are required to reduce uncertainty of temperature predictions for managing rivers in which fish at different life stages are highly sensitive to temperature fluctuations. As global climate patterns continue to elevate temperatures, the ability to predict the resulting small, yet significant, changes in water temperatures becomes important. The Virgin River was chosen for study because: 1) the broad range of summer air temperatures during low flow conditions provide for more extensive testing of instream temperature prediction capabilities; 2) the extensive knowledge of the river system from previous research of Dr. Thomas B. Hardy, Dr. Craig Addley, and the PI at USU, the Virgin River Program, the Washington County Water Conservancy District, the Utah Division of Wildlife Resources, and many others provide a rich historical backdrop against which data collection and model results may be interpreted and; 3) the equipment and infrastructure already in place in the river that minimizes data collection efforts.

Additionally, understanding the surface and subsurface storage interactions with the main channel advection is critical for understanding the fate and transport of constituents other than temperature. Past studies have attempted to quantify the effects of storage, specifically subsurface storage, on nutrients, arsenic, and heavy metals persistence in river systems. River restoration projects have tried to determine if the newly engineered river system mimics the dynamics of a natural river system in terms of hyporheic exchange and dead zones. These studies have used a one-zone modeling approach in the past, but have been unable to determine if the bed sediments are behaving in such a way as to promote the ecological health of the river system. The need to quantify the effects of surface and subsurface storage independently in rivers has been and continues to be identified as necessary to understand the processes occurring in streams and rivers (Harvey and Wagner 2000; Packman and Bencala 2000; Runkel and McKnight 2003).

Objectives

The overall focus of this research is to improve our understanding of the local scale energy and mass exchange processes taking place within a river. To do this, we expanded on the two-zone stream model for a conservative tracer and temperature developed at USU (Neilson 2006) by: collecting more spatially intensive data required for model calibration and corroboration under a number of flow regimes and; beginning to test the model/data collection system for differing flow conditions; and eventually determining if this more mechanistic approach to modeling instream storage provides for parameter transferability.

The overall purpose of this research is to further modeling techniques for river systems by developing a data collection and modeling approach that provides the ability to capture the effects of storage processes on instream temperatures, and ultimately other water quality constituents. To meet this overarching objective, three study objectives were developed.

1. *Design and implement a data collection system in the Virgin River.*

The design and implementation of the data collection system was based on the past efforts of Neilson (2006). Three data collection efforts at different flows were conducted to capture surface and subsurface storage dynamics under diverse flow regimes. Five cross sections consisted of temperature probes placed in locations representative of main channel temperatures, dead zone temperatures, and sediment temperatures. Tracer experiments using Rhodamine WT were conducted with data being collected at several cross sections within the river reach. At each cross section, samples were collected in the water column (main channel and dead zones) and in the substratum to determine the extent of dead zone and hyporheic exchange. Data regarding solar radiation behavior above and in the water column using an albedometer were also collected. Weather data was collected near the section of the river being studied and flow data was collected throughout the study section to ensure that all inflows and outflows were being accounted for. Data collected during early and mid-summer conditions will be presented in this report. Data from winter (February 2007) were presented as part of a previous 104(b) Report.

2. *Use the data collected for the Virgin River in Objective 1 to test the two-zone modeling approach.*

When modeling the effects of two storage zones, the number of calibration parameters grows due to more processes being represented. The data collected in the Virgin River will be used to populate, calibrate, and corroborate the two-zone temperature and solute model. Past efforts (Neilson 2006) have shown that solute concentrations and temperatures representing different zones can be used to assist in approximating parameters associated with both surface and subsurface storage zones. However, due to the resulting number of calibration parameters (> 8 for each river reach) and calibration time series (> 6 at each cross section due to temperature being measured at different locations in the water column and sediments), the two-zone temperature and solute model will be coupled with a mulit-objective automatic calibration algorithm (Multiobjective Shuffled Complex Evolution Metropolis (MOSCEM) (Vrugt et al. 2003)). This algorithm has been previously used to calibrate hydrologic models where multiple time series that represent unique characteristics of the system exist. MOSCEM was found to provide a robust way to estimate parameters for the two zone model and provides for an understanding of the model uncertainty associated with parameter estimates. This new data collected in the Virgin River will provide an independent test of the two-zone data collection and modeling approach given different storage characteristics due to diverse flow regimes. Due to the short timeframe associated with this project, the modeling efforts are only in the preliminary stages. Final modeling results will be included in an M.S. thesis and as a peer reviewed journal article.

3. *Examine the transferability of storage exchange and related parameters under different flow conditions and provide suggestions about approaches to better capture the effects of storage given dynamic flow conditions.*

One of the concerns associated with a one-zone approach to estimating the effects of transient storage on instream processes is the inability to transfer parameters that are estimated from a stream solute curve during one flow rate to other flow conditions. Since the two-zone modeling approach provides a more explicit description of the surface and subsurface mechanisms, it is hypothesized that the parameters estimated for one flow condition are better able to be transferred to other flow conditions. The different data collection efforts will provide the opportunity for testing that transferability between flow conditions and potentially provide information about improving the model structure so that dynamic flows can be considered. This research will occur once the modeling efforts are complete.

Project Results

System Description

Sampling locations were selected at data collection sites to represent different substrate and bottom slope conditions (see Table 1 and Figure 1). Figure 1 shows a schematic of the study portion of the Virgin River and the location of the inflows. The exit from a large horseshoe bend in the river approximately 17.5 km above the Washington Fields Diversion, labeled “Below Gould’s Wash,” was designated as the headwater and is referred to here as Cross Section (CS) #1. Stratton pond (CS #3-4) are low gradient runs located just upstream from Stratton Pond, which is a small impoundment that is utilized to hold the outflow of Quail Creek Reservoir and allow for an increase in temperature before being released into the Virgin River. Hurricane Bridge (CS #5) lies near the middle of the study reach and provides information about the higher gradient section of the study reach (see Figure 1). Pecan Fields (CS #6-8) lies 4.5 km downstream of CS #5 and provides information about the transition between the higher gradient section and the low gradient section that spans CS #6 and #11. The end of the study area is located above the backwater of the Washington Fields Diversion structure (CS #9-11).

Table 1. Temperature measurement site characteristics

Site	Substrate Description
CS #1 - Below Gould's Wash (GW1)	Tail of pool, transition to run, with mostly sand substrate.
CS #2 - Below Gould's Wash (GW2)	Riffle with compacted gravel and cobble, filled with sand
CS #3 – Stratton Pond (SP1)	Run/Low gradient with compact gravel/sand
CS #4 – Stratton Pond (SP2)	Run/Low gradient with compact gravel/sand
CS #5 - Hurricane Bridge (HB1)	Tail of pool, below large riffle with sand substrate
CS #6 – Pecan Farms (PF1)	Low gradient riffle with compacted gravel and coble, filled with sand
CS #7 – Pecan Farms (PF2)	Run/low gradient riffle with loose gravel/sand
CS #8 – Pecan Farms (PF3)	Run/low gradient riffle with loose gravel/sand
CS #9 – Washington Fields (WF1)	Low gradient riffle with compacted gravel and coble, filled with sand
CS #10 – Washington Fields (WF2)	Run/low gradient riffle with loose gravel/sand
CS #11 – Washington Fields (WF3)	Run/low gradient riffle with loose gravel/sand

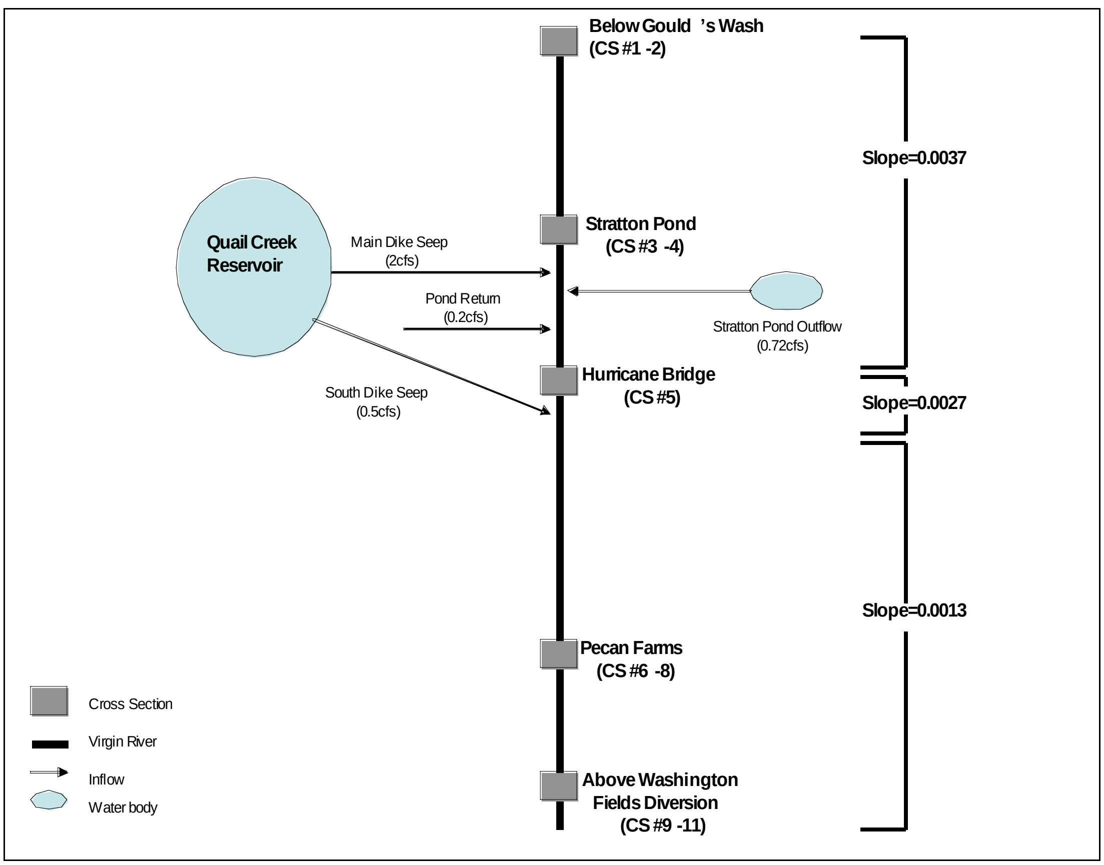

Figure 1. Layout of the portion of Virgin River sampled (not to scale) showing flow rates associated with external inflows and bottom slopes between sampling locations.

These preliminary data presented in this report were collected during two separate trips in May and June 2007; thus, enabling a comparison between early and mid-summer conditions. These data additionally coincide with data collected in February 2007, which represent the winter conditions of the study site.

Data Collection Methods:

Webb and Zhang (1997) state that despite the importance of understanding heat sources and sinks in systems for predicting water temperatures, few studies have collected *in situ* measurements of the energy balance components. In the Virgin River, data have and continue to be collected specifically for understanding the importance or relevance of different energy balance components that may affect predictive capabilities. In addition to collecting data regarding energy fluxes, other data were collected that are necessary to populate, parameterize, and test the temperature model.

At each site (Figure 1), Hobo® U22 Water Temp Pro v2 (Onset Corporation, Bourne, MA) temperature probes were placed in the water column and sediments to measure temperature at 5 minute intervals in CS #1 - #11. The accuracy of the Hobo® Water Temp ProV1 is ± 0.2 ^{o}C from 0 to 50 ^{o}C. Figure 2 shows the possible probe placement in each cross section. Probes #1 and #3 measure the temperatures of the dead zones. Probe #2 measures the main channel temperatures. Based on recommendations from Silliman and Booth (1993), probes #4 - #6 were buried at approximately 3, 9, and 20 cm to determine the depths at which sediment interacted with the water column and provide an understanding of the bed conduction and other possible heat sinks or sources in the sediments. Based on findings from Neilson (2006), three more probes (#7 - #9) were buried at each site in the substrate and were isolated from hyporheic flow by a metal cylinder as shown in Figure 2. These probes provided an independent measure of bed conduction and probes #4, #5, and #6 represented the combined effects of bed conduction and hyporheic flow. Figure 3 is a close up view of temperature probes #7 and #8 installed at CS #6 in the Virgin River during the June 2007 study.

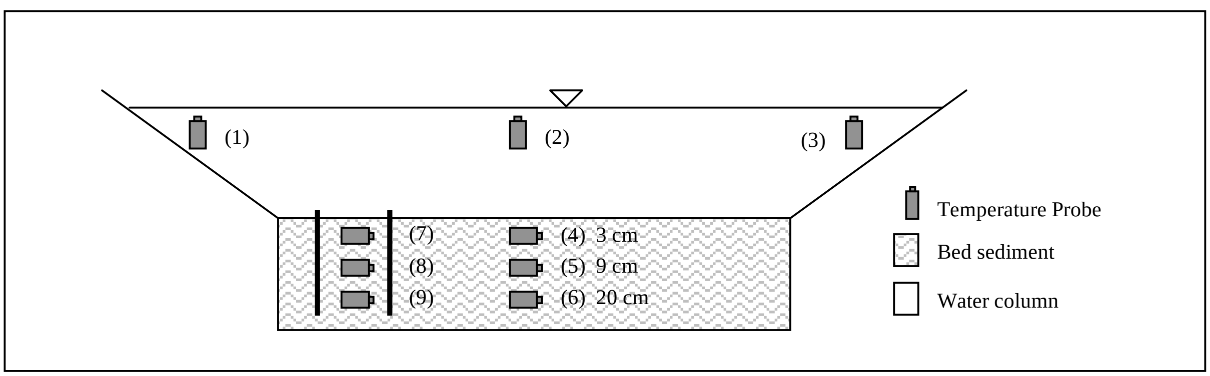

Figure 2. Locations of temperature probes at each of the three locations within the study reach.

Figure 3. Temperature probes installed in the substrate of Virgin River.

Slow moving or dead zones behind debris or along the edges of the channels can be sources and sinks of heat. In this study region of the Virgin River, a number of such zones were identified during preliminary surveys and tracer studies at the measurement sites. Temperature probes were placed in some of these slow moving areas to characterize the dynamics of energy exchange between the main channel and these dead zones, by measuring the difference in temperatures between probes # 2 and probes #1 and #3 as shown in Figure 2.

Probes #1, #2, and #3 were placed in the water column by anchoring them with rebar at approximately mid depth of the water column. Probes # 4 - #6 were attached to a long piece of PVC pipe placed over the rebar anchored in the center of the cross section. Up to four probes were attached externally to the PVC at the specified depths. An arm, made from a short piece of PVC, attached to the long piece of PVC indicated where the top of the bed sediment should be located in relations to the desired depths of the buried probes.

In conjunction with *in-situ* temporally continuous temperature data, spatial temperature data were obtained with airborne thermal infrared (TIR) imagery. TIR remote sensing is utilized to monitor ocean surface temperatures (Wick *et al.,* 1992; Emery and Yu, 1997), as well as lake surface temperatures (Ledrew and Franklin, 1985; Garrett *et al.,* 2001). Similar studies have been conducted on streams using high resolution (submeter) TIR imagery collected from low flying aircraft (Torgerson *et al.,* 2001). TIR imagery of the Virgin River was collected using remote sensing forward-looking infrared (FLIR) instrumentation mounted on a fixed-wing single prop aircraft. To avoid reflection created by bank materials, the TIR imagery was collected with a senor viewing geometry in which the stream was monitored as close to nadir as possible. *In situ* data collection methods provided temporally variable point temperatures, while TIR imagery captures spatial variations. This airborne TIR imagery provides a complete temperature profile of the studied reach of the Virgin River for the exact time collected. This provides information on restoration needs for fish habitat quality and potential refugia. It also can assist in improving model calibration and corroboration which provides for the understanding of temperature mitigation scenarios for a watershed. Torgersen *et al.* (1999) suggests that spatial data are needed to map sources of thermal heterogeneity at the watershed scale and identify biologically important areas such as thermal refugia. Analysis of the airborne TIR imagery collected on the Virgin River may prove beneficial in identifying thermal refugia, but for this study the focus of the thermal imagery is to enhance temperature model calibration and corroboration. The thermal imagery was corrected for atmospheric interference and was validated for accurate temperature readings using in-stream loggers. *In-situ* temperature measurements, recorded at the time thermal imagery was collected, were compared to corrected imagery temperatures to validate the values provided by the TIR imagery.

Data regarding the incoming shortwave solar radiation to the water column, the albedo of the water surface, the penetration of radiation through the water column to the substrate, and the reflection off the substrate were collected using an albedometer. The albedometer was fabricated from two CM3 pyranometers (Kipp and Zonen, Bohemia, NY) mounted to a plate with one facing up and one facing down to measure the incoming and reflected shortwave radiation. Hourly measurements of incoming and reflected shortwave radiation were collected just above the water surface, in the mid portion of the water column, and just above the bed surface. Additionally, attenuation measurements (determined using the measures of shortwave radiation at different depths in the water column) were taken several times daily to understand how the attenuation changes with the angle of the sun.

Piezometers were installed in the river substratum at CS #1 - #5 (Figure 1). At these cross sections, two piezometers were installed within the steel cylinders at 10 cm and 25 cm deep and two in the substrate adjacent the cylinders at the same depths. Two depths were chosen to: determine hyporheic activity at various locations in the substrate; measure vertical head gradient and hydraulic conductivity for each site; and provide a means to collect grab samples of water from the hyporheic zone throughout the duration of the tracer studies.

Groundwater-stream water exchange can be quantified by measuring the vertical head gradient (VHG) (Baxter and Hauer, 2003). VHG is a unitless measure that is positive during upwelling and negative under downwelling conditions. The VHG was calculated with the following equation; $VHG=\Delta h/\Delta l$, where Δh is the difference in head between the water level in the piezometer and level of the stream surface and Δl is the depth from the streambed surface to the first perforation in the piezometer sidewall. VHG were calculated for the CS #1 - #5 in order to enhance the understanding of groundwater-stream water exchange.

Water quality parameters such as temperature, dissolved oxygen, specific conductance, and pH were collected at CS #1 - #5 using a 600XLM (multi-parameter water quality probe) from *YSI Environmental Monitoring Systems Incorporated* (Yellow Springs, OH). At CS #1 and #2, the 600XLM was deployed in the open channel for approximately 20 hours and for 10 minutes at CS #3 - #5 to procure baseline water quality data. All four water quality parameters were logged continuously every five seconds for the duration of each individual deployment.

Along with the above water quality data, conductivity, temperature, and depth were recorded every five minutes for approximately 24 hour periods within the piezometers installed in the river substratum of cross section #1 and #2. Piezometers of CS #1 and #2 were installed in the river substratum inside the steel cylinder as well as outside. These parameters were recorded using multiple *In-Situ Aqua Trolls* (In-situ Inc. Ft. Collins, CO). These instruments were deployed in order to gather information regarding head fluctuations within the piezometers based on their location, within or without the cylinders.

Accomplishments and/or findings to date:

Temperature Data

Main Channel Temperatures

Figures 4 and 5 depict main channel temperatures (center of water column) at each cross section for the May and June studies. These plots show changes in instream temperatures longitudinally. For example, in Figure 4, Stratton Pond #2 (CS #4) is consistently warmer during peak solar radiation. This is likely due to an increase in channel width creating shallower main channel water depths and negligible riparian/topographic shading. CS #1 and #2 show greater water temperatures than CS #6-11. The probable causes for increases in temperatures at these locations is low instream flows that occur above the Stratton Pond effluent, the effects of Pah Tempe Hot Springs located above the study reach, and minimal hyporheic exchange due to compacted substrate. Therefore, with main channel temperature data at each cross section of the study reach we can determine what variables may be influencing the overall river temperature regime and their location.

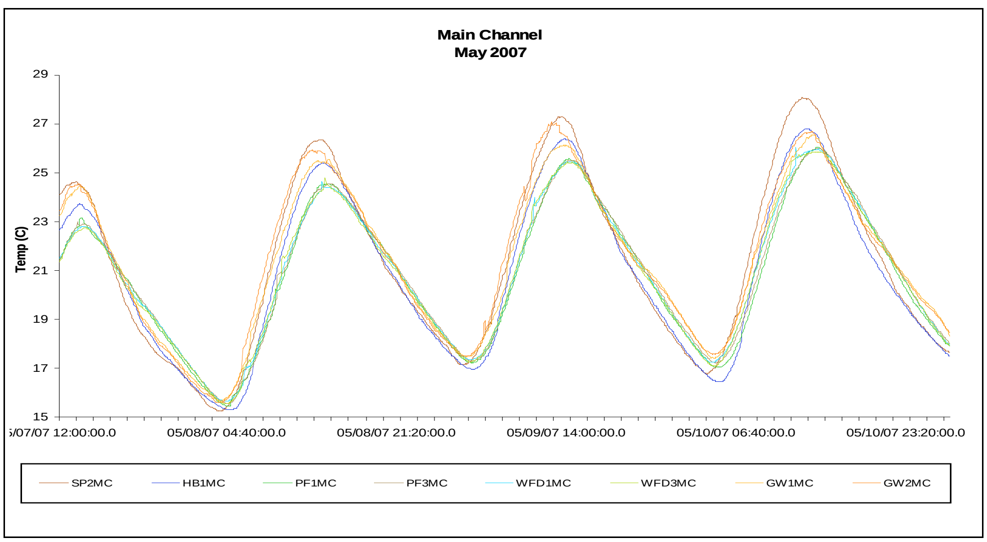

Figure 4. Main channel temperatures at each sampling site location for May 2007.

Figure 5 demonstrates similar temperature trends in June 2007 of those depicted in Figure 4 for May 2007. Stratton Pond #2 (CS #4) is consistently higher than all other cross sections during peak solar radiation. However, the peak temperatures in June 2007 increased by approximately 2˚C from those recorded in May 2007.

Dead Zone Temperatures

Dead zones are considered to be an important heat flux in the Virgin River. The recorded dead zone temperatures demonstrate the temperature differences between slow flow regions and the main channel of the river (Figure 6 and 7). Dead zone temperatures were measured at CS #1, CS #3, CS#5, and CS #11 for both May and June 2007.

Figure 6 and 7 show the range of temperature differences from the dead zone and main channel probes. Figure 6 shows there is little difference in main channel and dead zone temperatures at Hurricane Bridge (CS#5). Figure 7, however, shows that the main channel temperatures have smaller diurnal fluctuations than the dead zone temperatures at CS #3 in June 2007. This suggests that in lower gradient portions of the system where the channel is wide, shallow, and has slower main channel velocities, dead zones have a tendency to heat up during the day and cool more at night than the main channel. This may indicate that lateral mixing is dominated by diffusion rather than advection in some cases.

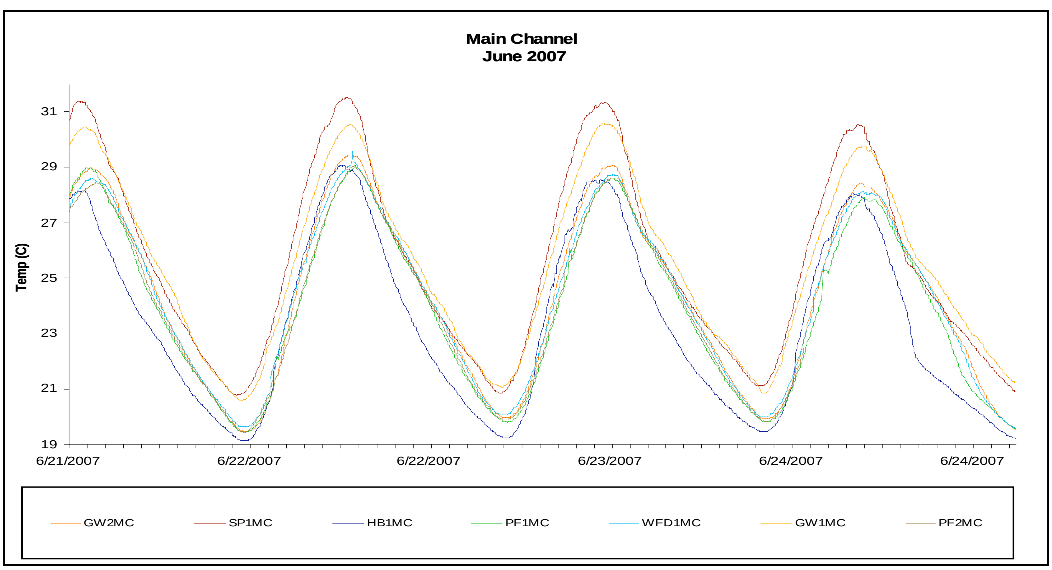

Figure 5. Main channel temperatures at each sampling site location for June 2007.

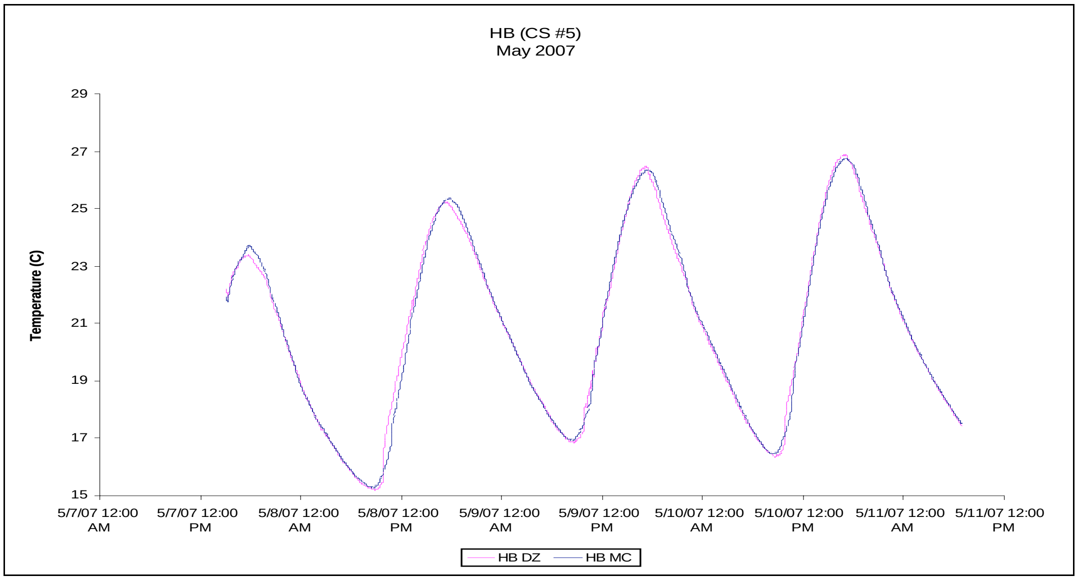

Figure 6. Comparison of main channel and dead zone temperature at CS #5 during the span of approximately 4 days in May 2007.

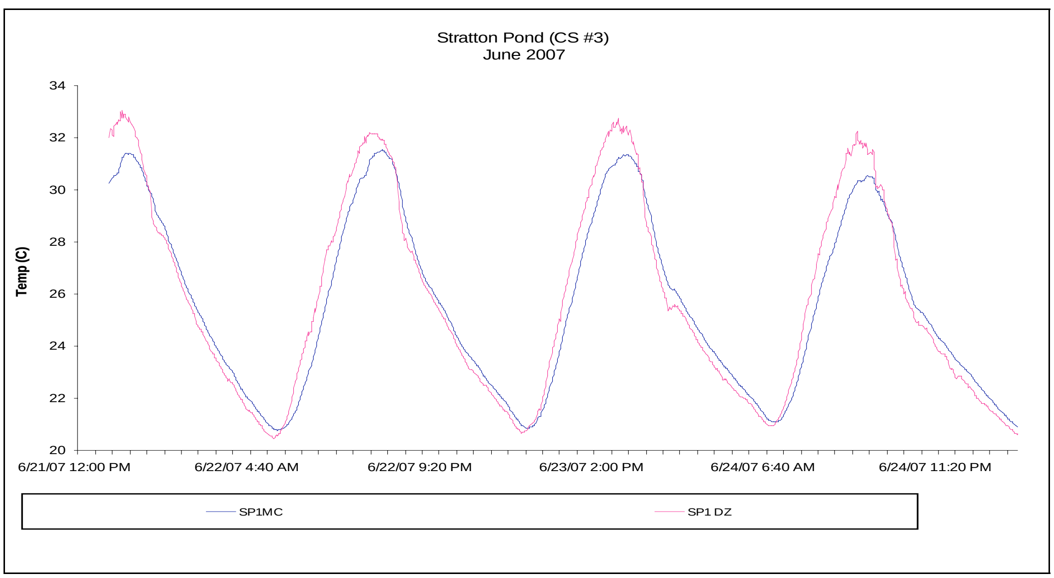

Figure 7. Comparison of main channel and dead zone temperature at CS #3 during the span of approximately 4 days in June 2007.

Conduction/Hyporheic Temperatures

The probes buried in the sediment produced different results at each cross section. Figure 8 and 9 show the temperature results for the probes buried in the substrate at CS #5 and 9. The time series labeled “conduction” represent the probes deployed in the metal cylinder which capture the effects of conduction and vertical heat exchange in the sediments. Those labeled “hyporheic/conduction” represent those that were buried outside of the cylinder and therefore, represent the effects of both conduction and hyporheic exchange. It is expected that the values for hyporheic/conduction probes will differ from the conduction probes if hyporheic exchange is occurring.

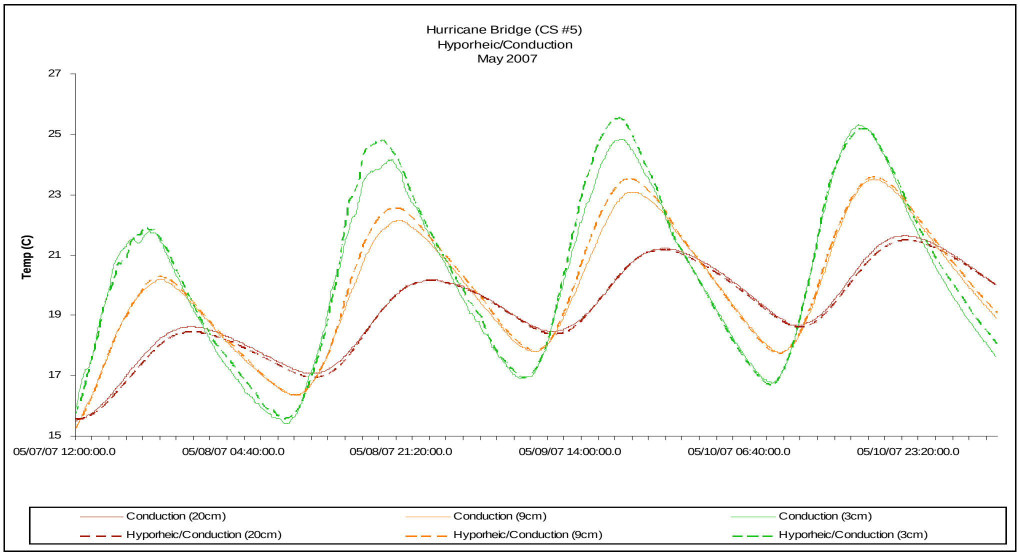

Figure 8. Measured temperatures related to conduction and hyporheic/conduction of the river substrate at CS #5 for May 2007.

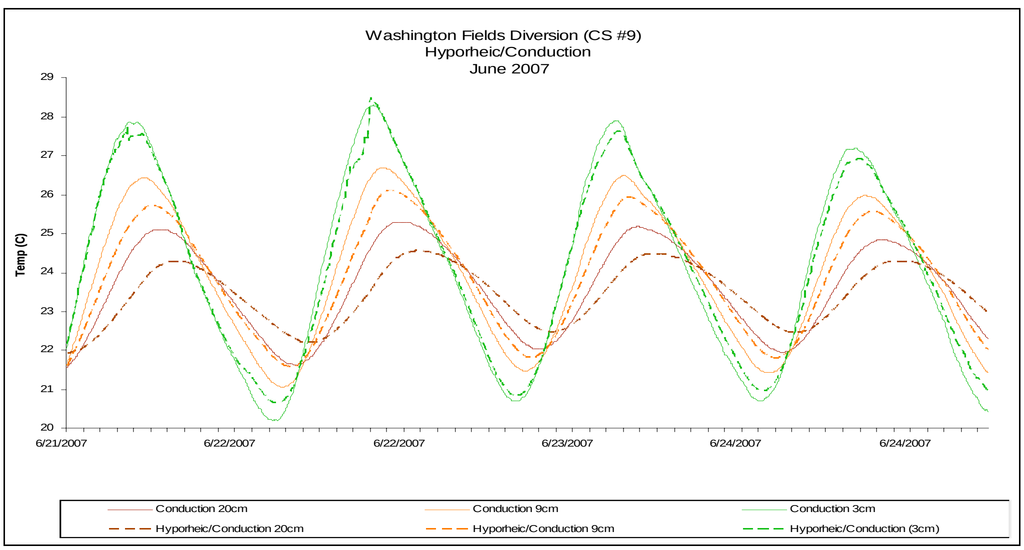

Figure 9. Measured temperatures related to conduction and hyporheic/conduction of the river substrate at CS #9 for June 2007.

All Temperature

Figures 10 through 12 show all temperature probes placed at CS #1 and #4 for June 2007 and CS #6 for May 2007. These plots help visualize how temperatures differ at varied depths in the river substrate and how conduction versus hyporheic/conduction may vary. With this data, trends between cross sections and various sediment depths can be determined. This can facilitate the identification of temperature impairment locations and the potential causes.

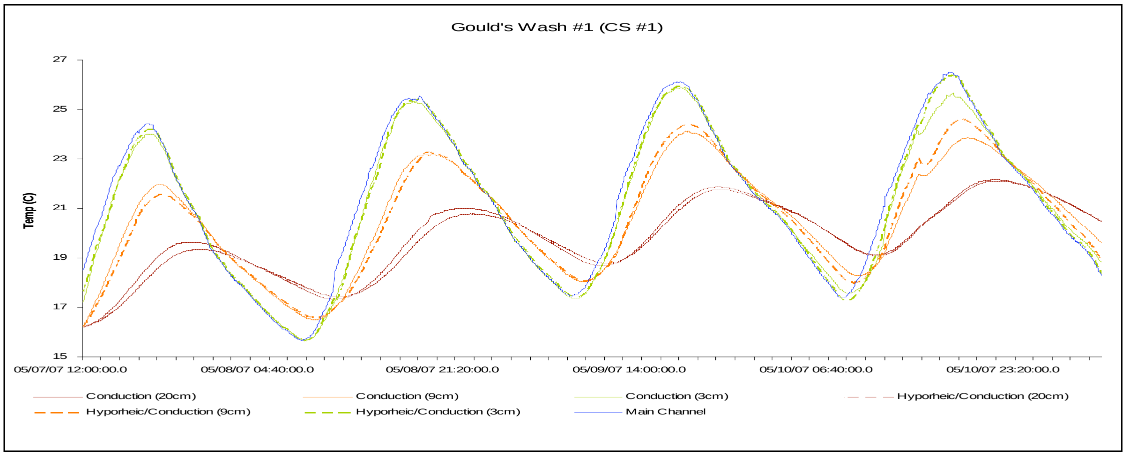

Figure 10. All temperature measurements recorded at CS #1 for June 2007.

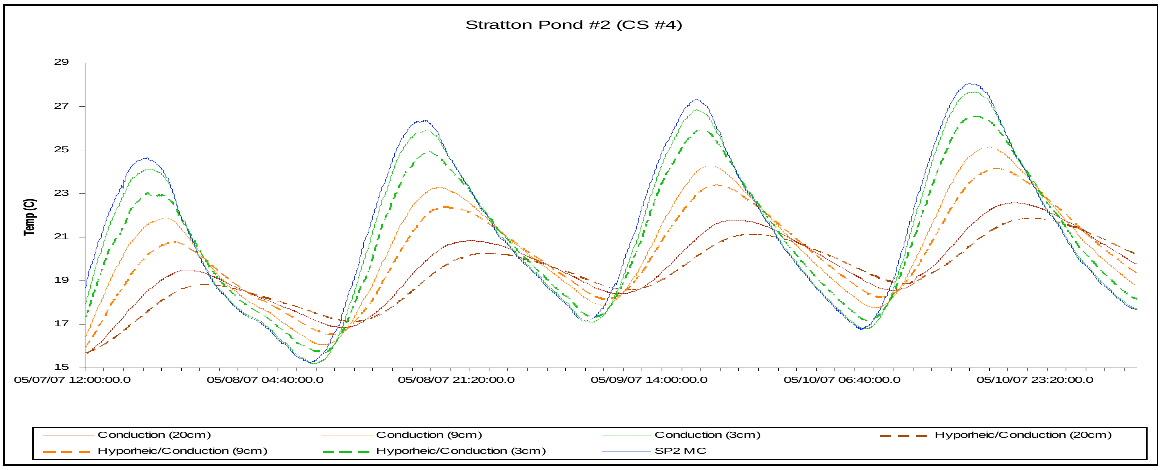

Figure 11. All temperature measurements recorded at CS #4 for June 2007.

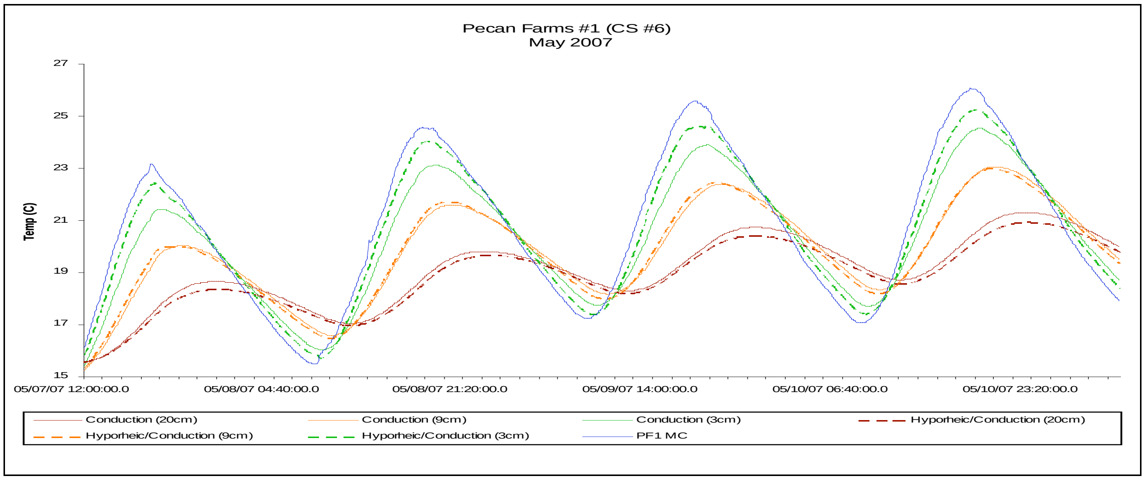

Figure 12. All temperature measurements recorded at CS #6 for May 2007.

Albedometer Data

Figures 13 -18 show the albedometer readings for May 8th through May 10th and for June 22nd through June 24th. The solid lines represent the incoming shortwave radiation values for the top pyranometer at three different locations (above the water surface, in the middle of the water column, and at the bottom of the water column just above the river substrate). The dashed lines represent the corresponding reflected shortwave radiation measurements from the bottom pyranometer. Solar radiation is a main contributor of heat to the Virgin River, therefore, the knowledge and understanding of shortwave attenuation through the water column is invaluable to comprehend the nature of the river's temperature regime.

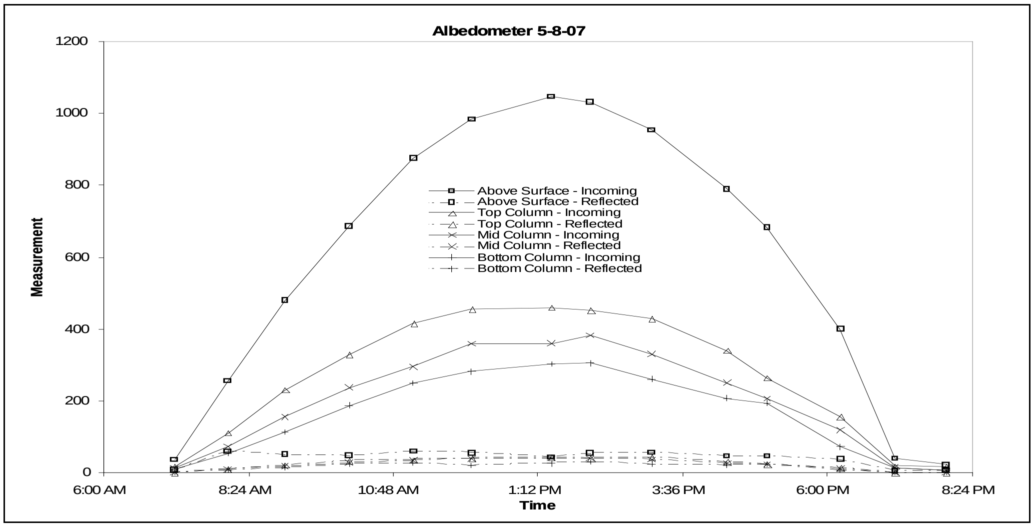

Figure 13. Albedometer readings from May 8, 2007.

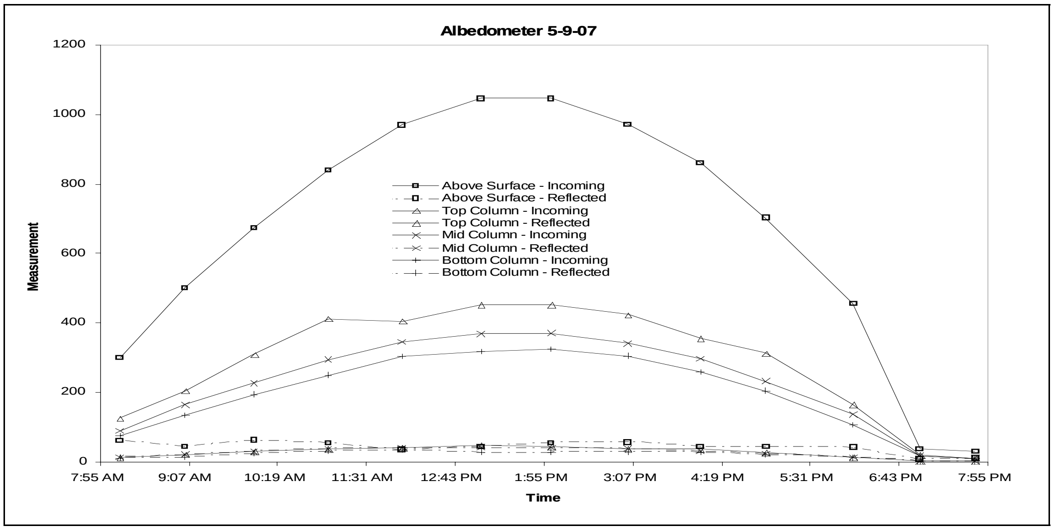

Figure 14. Albedometer readings from May 9, 2007.

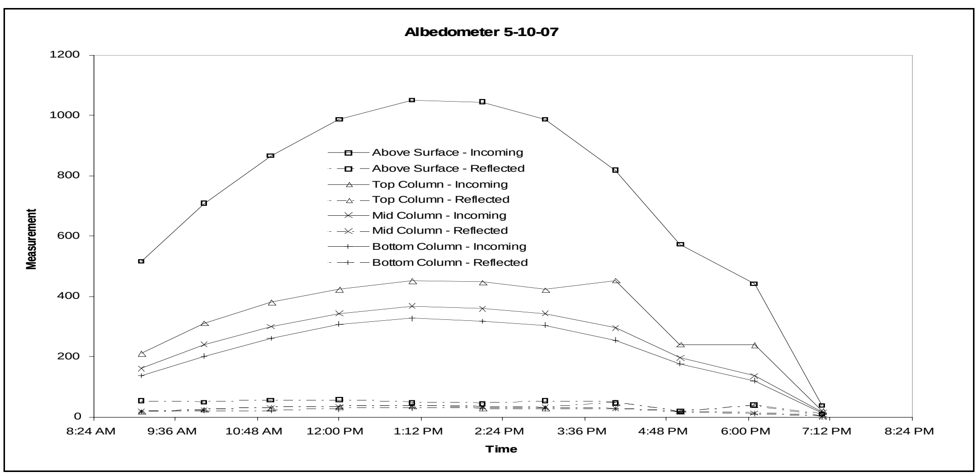

Figure 15. Albedometer readings from May 10, 2007.

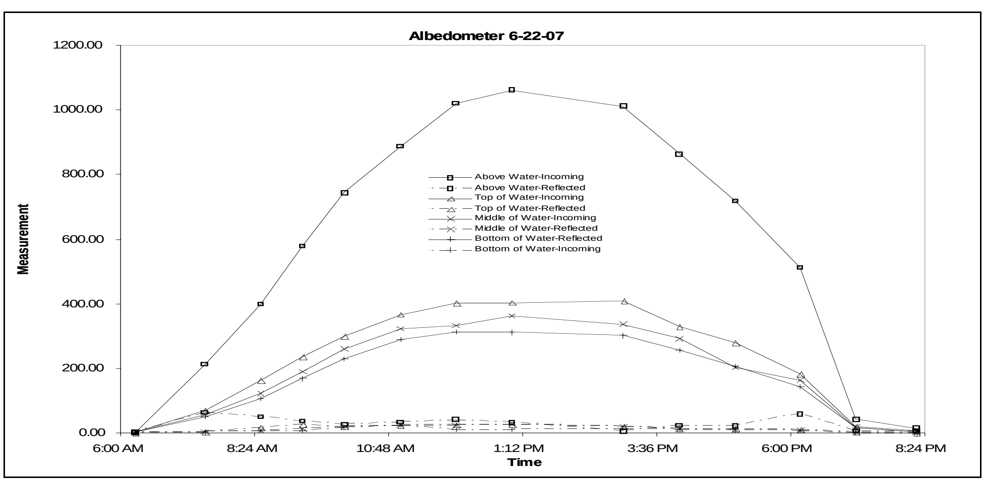

Figure 16. Albedometer readings from June 22, 2007.

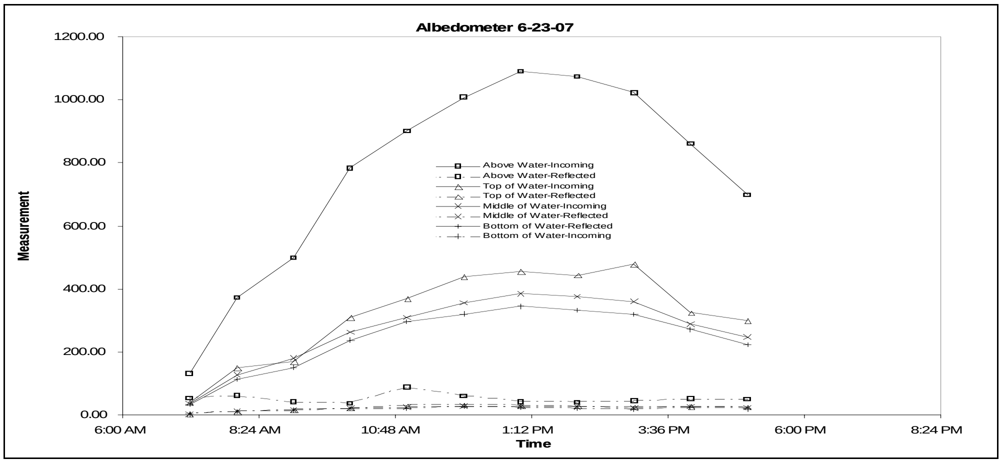

Figure 17. Albedometer readings from June 23, 2007.

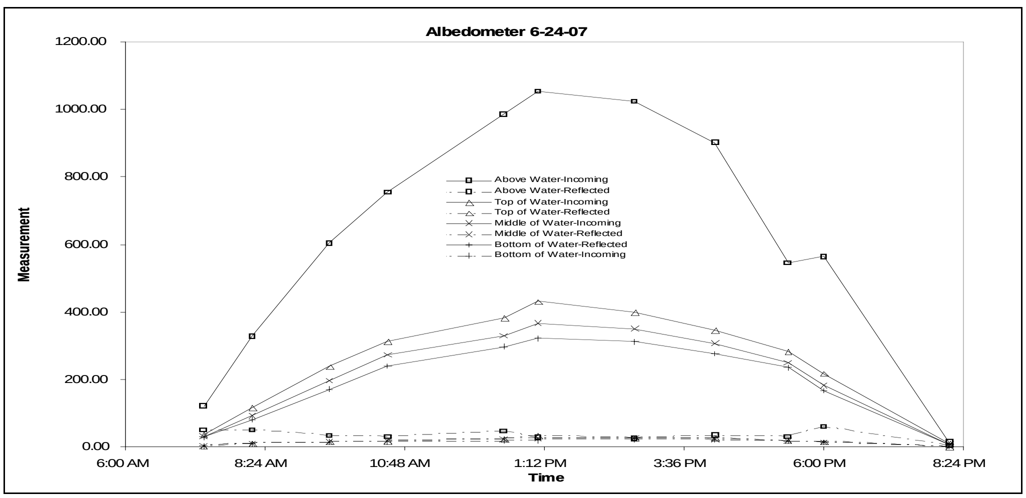

Figure 18. Albedometer readings from June 24, 2007.

Tracer Data

Tracer studies were conducted in both May and June. Slugs of rhodamine WT dye were added at CS #1 and measured at two cross section locations downstream. Figure 19 and 20 show the tracer study results at CS #4 and CS #5 for the main channel and two dead zones that were sampled. These data provide information about travel times, dead zone exchange (as shown by the lag in the dead zone concentrations), and hyporheic exchange (as shown by the tail of the curve).

Figure 21 shows the visual appearance of the river once rhodamine WT dye is introduced to the water column. The dye gives the river a pink tint and the tint becomes progressively faint as dispersion occurs. The apparatus in the lowers left corner of the picture is the fluorescing apparatus utilized to measure concentrations over time.

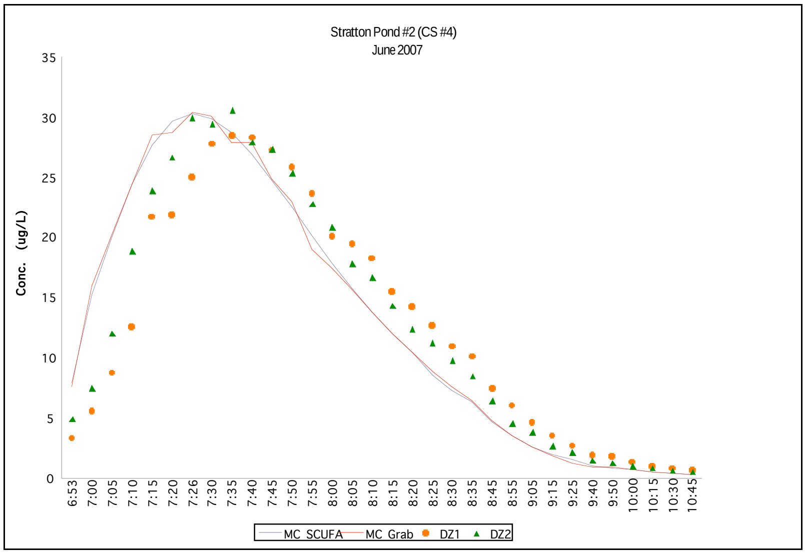

Figure 19. Tracer data at CS #4.

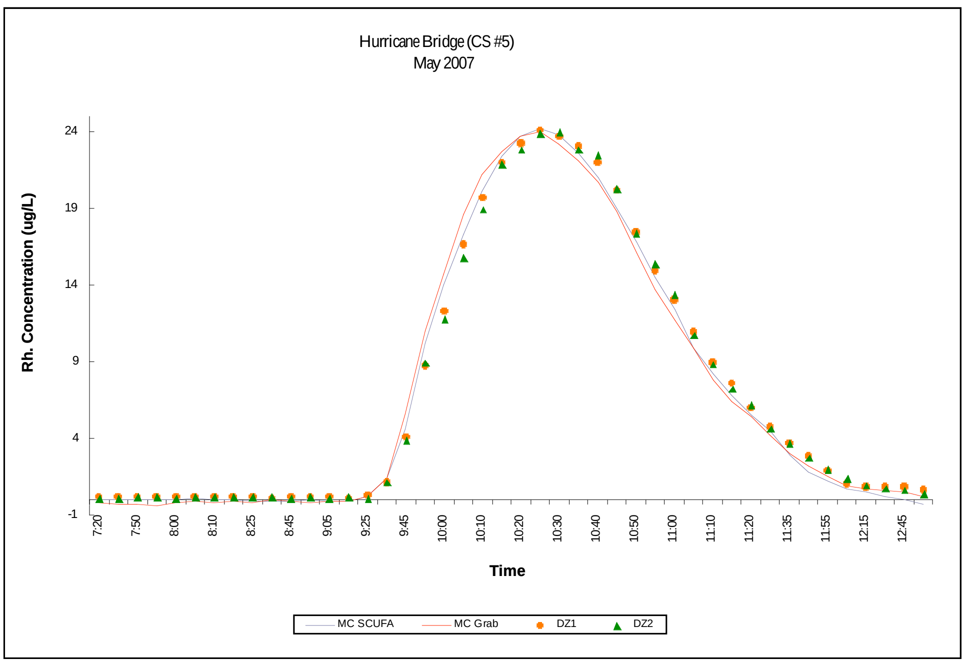

Figure 20. Tracer data at CS #5.

Figure 21. Shows the results of rhodamine WT.

Vertical Head Gradient

As mentioned previously, vertical head gradients (VHG) were calculated for CS #1 - #5 via piezometers installed in the river substratum. Table 2 contains the calculated vertical head gradient for CS #3. From the calculated VHG of CS #3 it is apparent that little upwelling or downwelling is occurring at this location during the study conducted June 2007.

Along with VHG calculations, *In-Situ Aqua Trolls* were deployed with the piezometer of CS #1- #2 to determine how upwelling and downwelling fluctuated over time. Figure 22 is the data recorded from one piezometers at CS #1. The installation depth of this piezometer was 10cm and was not contained within a steel cylinder. A diel fluctuation in temperature is apparent in this plot, along with a fluctuation in depth. The depth fluctuation indicates influence of groundwater-stream water exchange.

Table 2. Calculated VHG for CS #3. Labeling description: B denotes a piezometer installed within a steel cylinder, the number following (10 or 25) is the installation depth, and the last number denotes the piezometer diameter. NB denotes piezometer install in the substrate without the cylinder encasing.

Peizo.	In Depth (ft)	Out Depth (ft)	_l (ft)	_ h (ft)	VHG
B10 2"	2.7	2.72	0.328	0.020	0.061
B10 1"	1.48	1.48	0.328	0.000	0.000
B25 1"	1.65	1.63	0.820	-0.020	-0.024
NB10 2"	2.31	2.3	0.328	-0.010	-0.030
NB25 2"	1.81	1.79	0.820	-0.020	-0.024
NB10 1"	1.2	1.2	0.328	0.000	0.000
NB25 1"	0.68	0.68	0.820	0.000	0.000

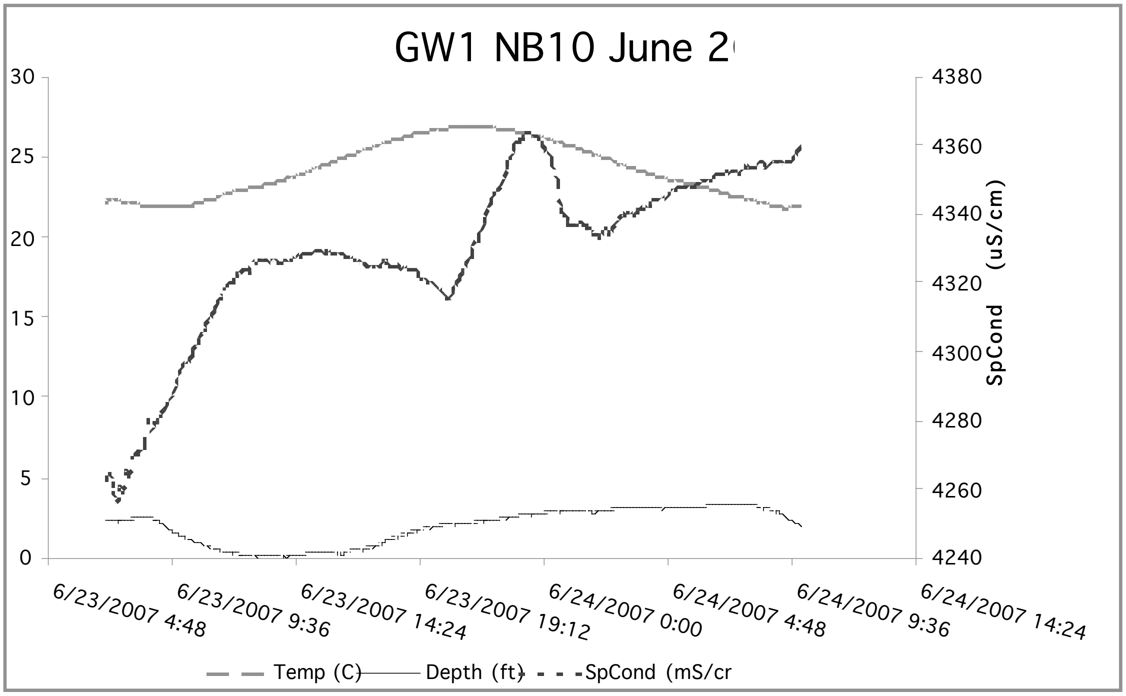

Figure 22. Plot of depth, temperature, and specific conductance recorded within piezometer installed at 10 cm in the river substratum at CS #1.

Conclusion

The data presented above provide valuable information about energy fluxes within the main channel of the river, the dead zones, and hyporheic zone. This data was procured in order to facilitate the understanding of each fluxes significance and influence on in-stream temperatures. Main channel temperatures and tracer data were collected congruently with dead zone temperatures and tracer data to provide an understanding of the exchange of energy and mass between the two zones. Sediment temperature probes, installed in the substratum, supplied information regarding sediment interaction with the water column. A number of temperature probes were placed in a steel cylinder to allow for the approximation of the bed conduction flux.

Incoming shortwave solar radiation to the water column, the albedo of the water surface, the attenuation of short wave solar radiation in the water column, and the reflection off the substrate which were all collected via an albedometer. These data aid in calculating the dominant shortwave radiation flux into the water column and the potential for sediment warming due to solar radiation penetrating the water column.

Based on accuracy and uncertainty studies of thermal-infrared remote sensing of stream temperature conducted by Cherkauer *et al.* (2005) and Handcock *et al.* (2005), the minimum number of pixels across the stream width for minimizing error and measuring accurate instream temperature readings is three pixels. Increasing the image resolution (number of pixels) reduces the error in predicting instream temperatures. Error is induced when a high ratio of pixels that includes both bank materials (riparian vegetation, dirt, rocks, etc.) and water exists. In the case of the TIR imagery collected for this study reach of the Virgin River, the resolution (one meter) is ~10-20 pixels across, therefore exceeds the minimum. Therefore, the TIR imagery collected for this study is adequate and will facilitate the calibration and corroboration of the temperature model of the studied reach of the Virgin River.

Calculated vertical head gradients in conjunction with temporal depth measurements from within piezometers has aided in determining which reaches of the study sight were experiencing upwelling or downwelling. By gaining a comprehension of groundwater-stream water interaction, the determination of sources and sinks of heat within the study reach of the Virgin River may be improved.

This diverse data set, collected over a ~17 kilometer study reach of the Virgin River, has provided a unique understanding of sources and sinks of heat in this system and the importance of various heat transfer processes. Future two zone temperature and solute model population, testing, calibration, and corroboration for the Virgin River will continue to provide insight and understanding into the dominant processes in different portions of the study reach.

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Information Transfer Program Introduction

The individual research projects documented in the Research Project section of this report have integrated within them information and outreach components. These include publication of research findings in the technical literature and provision of findings and water management models and tools on the web pages of the Utah Center for Water Resources Research (UCWRR) and individual water agencies.

Beyond this, Information Transfer and Outreach activities through the UCWRR, the Utah Water Research Laboratory (UWRL), and Utah State University (USU) have had an impact on the technical and economic development of the State of Utah. As part of the UCWRR outreach activities supported by USGS 104 funds, there continues to be a vigorous dialogue and experimentation with regard to efficiency and effectiveness of outreach activities of the UCWRR. Faculty are engaged in regular meetings with State of Utah water resources agencies, including the Department of Environmental Quality (DEQ), the Department of Natural Resources (DNR), and the State Engineer's Office to provide assistance in source water protection, on−site training, non−point source pollution management, technology transfer, development of source water protection plans (SWPPs), and efficient management of large water systems within the context of water−related issues in Utah.

UCWRR staff through the facilities at the UWRL, provides short courses both on− and off−site within the State of Utah, regionally, and internationally. Generally offered from one− to five−days duration, short courses are tailored to meet the needs of the requestor. The following is a partial list of short courses, field training, and involvement of UCWRR staff in information transfer and outreach activities.

Short Courses

Level I: Renewal of Certification: “Soil Evaluation and Percolation Testing.” Utah On−Site Wastewater Treatment Training Program. Richfield, Utah. March 2007. J.L. Sims.

Level II: Renewal of Certification: “Design, Inspection, and Maintenance of Conventional Systems.” Utah On−Site Wastewater Treatment Training Program. Richfield, Utah. March 2007. J.L. Sims.

Level III: Renewal of Certification: “Design, Inspection, and Maintenance of Alternative Systems.” Utah On−Site Wastewater Treatment Training Program. Logan, Utah. March 2007. J.L. Sims.

“Septic Systems 101 for Homeowners.” Utah On−Site Wastewater Treatment Training Program. Huntsville, Utah. March 2007. J.L. Sims.

“Septic Systems 101 for Homeowners. “ Utah On−Site Wastewater Treatment Training Program. Huntsville, Utah. April 2007. J.L. Sims.

Level I: Certification: “Soil Evaluation and Percolation Testing.” Utah On−Site Wastewater Treatment Training Program. Ogden, Utah. April 2007. J.L. Sims.

Level I: Renewal of Certification: “Soil Evaluation and Percolation Testing.” Utah On−Site Wastewater Treatment Training Program. Ogden, Utah. April 2007. J.L. Sims.

Level I: Renewal of Certification: “Soil Evaluation and Percolation Testing.” Utah On−Site Wastewater Treatment Training Program. Provo, Utah. April 2007. J.L. Sims.

Level II: Renewal of Certification: “Design, Inspection, and Maintenance of Conventional Systems.” Utah On−Site Wastewater Treatment Training Program. Ogden, Utah. April 2007. J.L. Sims.

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Level III: Certification: “Design, Inspection, and Maintenance of Alternative Systems.” Utah On−Site Wastewater Treatment Training Program. Logan, Utah. May 2007. J.L. Sims.

“The Theory and Application of the Physical Habitat Simulation System Habitat Time Series and Project Scenario Evaluations (PHABSIM − Windows).” Utah State University, Logan, Utah. June 2007. T.B. Hardy.

“BASINS/HSPF Training.” Environmental Management Research Group. Santa Clara, California. June 2007. B.T. Neilson.

Principal Outreach Publications

Principal outreach items include the Comprehensive Water Education Grades K−6 manual (several thousand copies of the manual have been distributed throughout the country, and distribution is now being planned in the United Kingdom and Australia), newsletters addressing the on−site wastewater issues (Utah WaTCH), and Mineral Lease Report to the Utah Office of the Legislative Fiscal Analyst.

Other publications from the UCWRR and UWRL appear regularly as technically−reviewed project reports, professional journal articles, other publications and presentations, theses and dissertation papers presented at conferences and meetings, and project completion reports to other funding agencies.

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR−USGS Internship	Supplemental Awards	Total
Undergraduate	5	0	0	0	5
Masters	1	0	0	0	1
Ph.D.	0	0	0	0	0
Post−Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Judith L. Sims, Utah State University engineering professor was recently elected to the board of directors for the National On−Site Wastewater Recycling Association (NOWRA). Professor Sims is a researcher at USU's Utah Water Research Laboratory. As a member of the board of directors, Professor Sims serves on the education committee and editorial board and will participate on committees that promote the educational activities of NOWRA.

Dr. David S. Bowles, Utah State University engineering professor was recently named a Diplomate, Water Resources Engineer (D.WRE) of the American Academy of Water Resources Engineers (AAWRE). In addition, Dr. Bowles was also awarded a certificate of appreciation for patriotic civilian service to the United States Department of the Army.

Dr. Bethany Neilson was selected as the first place recipient of the Universities Council on Water Resources (UCOWR) Ph.D. Dissertation Award for 2007 in the field of Natural Science and Engineering. The title of her Dissertation is *Dynamic Stream Temperature Modeling: Understanding the Causes and Effects of Temperature Impairments and Uncertainty in Predictions*. Her award was presented at the Awards Banquet during the UCOWR's Annual Conference held in Boise, Idaho on July 25, 2007.

Dr. Laurie McNeill won "Professor of the Year" for 2007 at the 49th annual Robins Awards held April 21, 2007. These awards are the most prestigious honor bestowed on contributors to Utah State University. At the acceptance of her award, Dr. McNeill said: "I would like to dedicate this honor to my friends and colleagues at Virginia Tech and encourage everyone here to work for peace.

Dr. Randal Martin received an award for being "Utah State University's 2007 Engaged Scholar" in recognition of service learning. This award was presented to Dr. Martin by Dr. Stan Albrecht, President of Utah State University, at the Utah Campus Compact's ceremony on April 3, 2007 at the Utah State Capitol in Salt Lake City, Utah.

Dr. Jagath Kaluarachchi was presented with the Utah State University Faculty Researcher of the Year Award for 2007 for the College of Engineering. The Researchers of the Year awards, presented to a faculty member in each College, are engaged in research projects that solve real, practical problems for people in Utah and throughout the world. Dr. Kaluarachchi was recognized this year during the Annual Research Awards Luncheon held by the Vice President for Research Office. Dr. Kaluarachchi's research specialty lies in groundwater hydrology and quality for water resources planning and management.

Publications from Prior Years

1. 2004UT46B ("Data Fusion for Improved Management of Large Western Water Systems") − Articles in Refereed Scientific Journals − Khalil, A., M.N. Almasri, M. McKee, and J.J. Kaluarachchi (2005). Applicability of statistical learning algorithms in groundwater quality modeling. *Water Resources Research,* 41 (W05010).
2. 2004UT46B ("Data Fusion for Improved Management of Large Western Water Systems") − Articles in Refereed Scientific Journals − Khalil, A., M. McKee, M. Kemblowski, and T. Asefa (2005). Sparse Bayesian learning machine for real−time management of reservoir releases. *Water Resources Research,* 41 (W11401).
3. 2004UT46B ("Data Fusion for Improved Management of Large Western Water Systems") − Articles in Refereed Scientific Journals − Khalil, A., M. McKee, M. Kemblowski, and T. Asefa (2005). Basin scale water management and forecasting using artificial neural networks. *Journal of the American Water Resources Association,* 41(1):195−208.
4. 2004UT46B ("Data Fusion for Improved Management of Large Western Water Systems") − Articles in Refereed Scientific Journals − Gill, M.K., T. Asefa, M. Kemblowski, and M. McKee (2006). Soil moisture prediction using support vector Machines. *Journal of the American Water Resources Association,* 42(4):1033−1046.
5. 2004UT46B ("Data Fusion for Improved Management of Large Western Water Systems") − Articles in Refereed Scientific Journals − Kaheil, Y.H., M.K. Gill, M. McKee, and L. Bastidas (2006). A new Bayesian recursive technique for parameter estimation. *Water Resources Research,* 42 (W08423).
6. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") − Articles in Refereed Scientific Journals − Gill, M.K., Y.H. Kaheil, M. McKee, and L. Bastidas (2006). Multiobjective particle swarm optimization for parameter estimation in hydrology. *Water Resources Research,* 42 (W07417).
7. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") − Articles in Refereed Scientific Journals − Khalil, A., M. McKee, M. Kemblowski, T. Asefa, and L. Bastidas (2006). Multiobjective analysis of chaotic dynamic systems with sparse learning machines. *Advances in Water Resources,* 29:72−88.
8. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") − Articles in Refereed Scientific Journals − Gill, M.K., T. Asefa, Y. Kaheil, and M. McKee (2007). Effect of missing data on performance of learning algorithms for hydrologic predictions: Implications to an imputation technique. *Water Resources Research,* 43 (W07416).
9. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") − Articles in Refereed Scientific Journals − Kaheil, Y.H., M.K. Gill, M. McKee, E. Rosero, and L.A. Bastidas (2007). Downscaling and assimilation of surface soil moisture using ground truth measurements. *IEEE Transactions on Geoscience and Remote Sensing,* TGRS−2007−00309.R3.
10. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") − Articles in Refereed Scientific Journals − Gill, M.K., M.W. Kemblowski, and M. McKee (2007). Soil Moisture Data Assimilation using Support Vector Machines and Ensemble Kalman Filter. *J. American Water Resources Association*, 43(4):1004−1015.