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Expected Water Surface Levels for the Great Salt Lake

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EXPECTED WATER SURFACE LEVELS FOR THE GREAT SALT LAKE

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ABSTRACT

Flooding at the Great Salt Lake could become a major disaster through the high cost of coping with the rising level, sudden collapse of protective levees, failure of pumping to the West Desert to induce increased evaporation, or, fiscally, by a rapid drop in the lake level just after a large protective expenditure. Hydrologist must provide timely and reliable information to assist decision making in the private sector, provide for the design of hydrologically safe levees, and optimize pumping schemes for moving water within a partitioned lake. Doing so will require crossing major theoretical frontiers in the study of basin scale hydrology in an arid climate and for forecasting extreme high flows over extended periods.

Key Words: Terminal lakes, Flooding, Levees, Arid basin hydrology.

INTRODUCTION

In the last four years, a 12-foot rise in the surface level of the Great Salt Lake has dealt a major blow to the Utah economy. Concerns voiced by the salt companies and railroads nearest the lake over a more gradual rise erupted in 1982 into levee failures and large economic losses. Millions of dollars were invested by industry and government in protection schemes, but the lake is still rising and approaching a level where the damages could increase by an order of magnitude. The situation could become a major disaster in at least four ways:

1. The cost of coping with added rise becomes astronomical. Billions of dollars could be spent on protecting or relocating Interstate Highways 80 and 15, the major transcontinental lines of the Southern Pacific and the Union Pacific Railroads, the Salt Lake International Airport, and innumerable other facilities. Plans for development of the prime industrial and commercial locations in a major metropolitan area would be derailed.

2. The principal method of protecting threatened properties is to build levees to the height needed to withstand projected short-term rises in lake levels. No one wants to spend more than will be needed. However, as the lake rises, the levees have to be raised too. Should the height and weight of the levee exceed the bearing capacity of the foundation, the piecemeal construction would suddenly collapse due to structural failure in the underlying mud. Greater risks also exist of liquefaction during an earthquake and overtopping by storm waves. Large industrial losses have already come through levee failure, and the failure of levees now being built could cause a major loss of life in residential areas.

3. The principal approach to lake level control is to expand the evaporative surface by on pumping excess water to the Western Desert. However, the $60-million scheme would prove ineffective if we have underestimated the net evaporation added by the larger surface area or if substantial runoff would enter from the West with wetter climatic conditions.

4. Tens or hundreds of millions of dollars could be spent on coping, protective, and control schemes only to lake peacefully recede short of where they are needed.

The role of the hydrologist in this situation is to provide information on long term (5 to 25 years) lake level probabilities for cost effective designs and lakeshore land use planning and on short term (up to 5 years) lake level movements for systems operations and industrial management decision making. Lake level forecasting is not an established art. Consequently, hydrologic science is challenged by needs to explore unfamiliar phenomena and develop new methodology. This paper examines current hydrologic methods in terms of the information they provide for achieving management goals and suggests hydrologic needed advances.

LAKE HYDROLOGIC HISTORY

Over the last 140 years Great Salt Lake levels have fluctuated, seasonally and over longer cycles, as shown in Figure 1. In 1963, the Lake shrunk to the minimum area shown in Figure 2. Now, state and federal agencies are seriously studying evaporation of a much larger runoff from a multi-level, compartmentalized system. For over 70 years (records before 1910 are incomplete), the only surface inflow entered the Lake from the Wasatch Mountains to the East. Now, we must recognize the hydrologic unity of a much larger portion of the Great Basin that is beginning to contribute significant runoff. The fluctuation in the physical dimensions of the lake is shown in Table 1. Climatic data for the last 5 years show high precipitation, below normal evaporation, fantastically high runoff, and an unprecedented rise in annual peaks (Table 2). During an earlier wet period (1862-1872), the mean streamflow of 2,947,000 acre feet was tested significantly higher than that during the other years from 1951 through 1981.

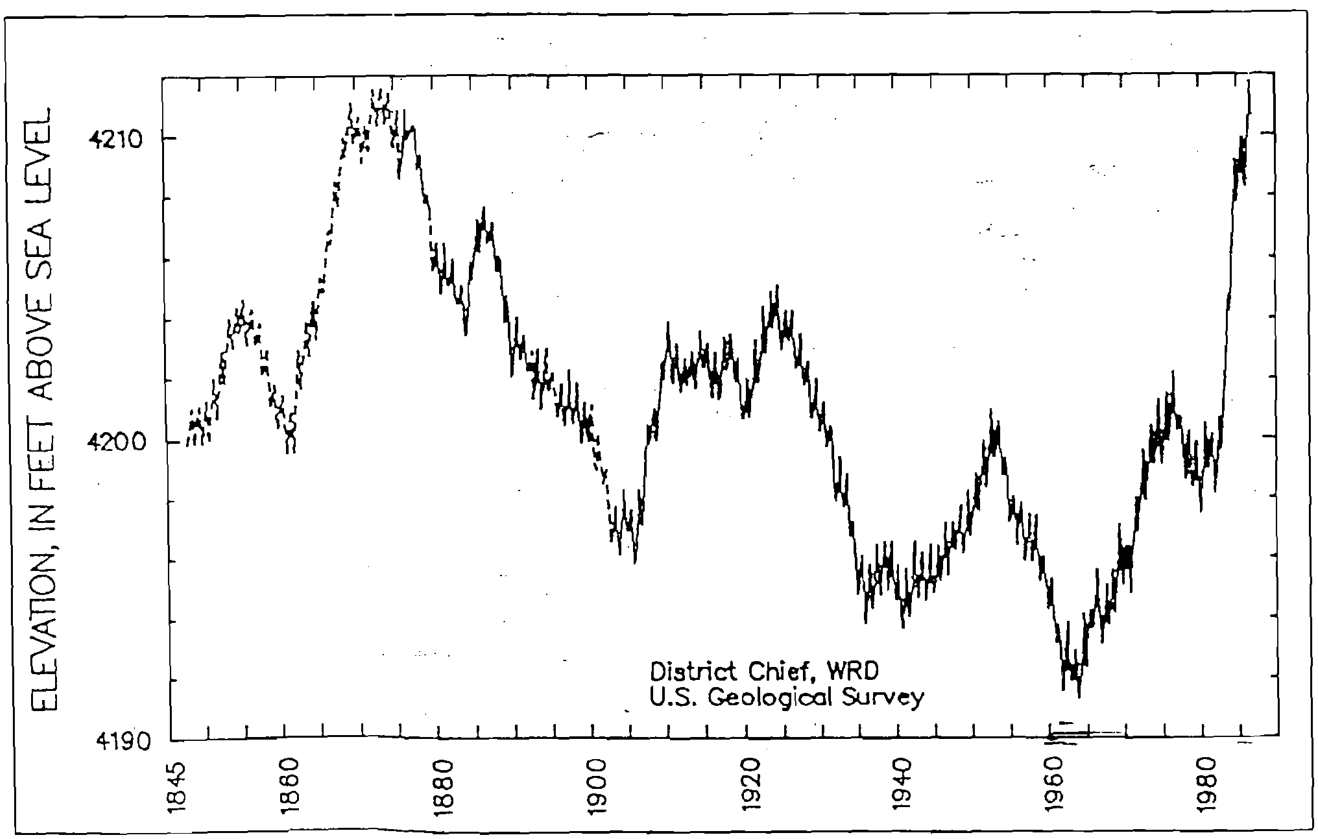

FIGURE 1. Great Salt Lake Fluctuations 1847-1986.

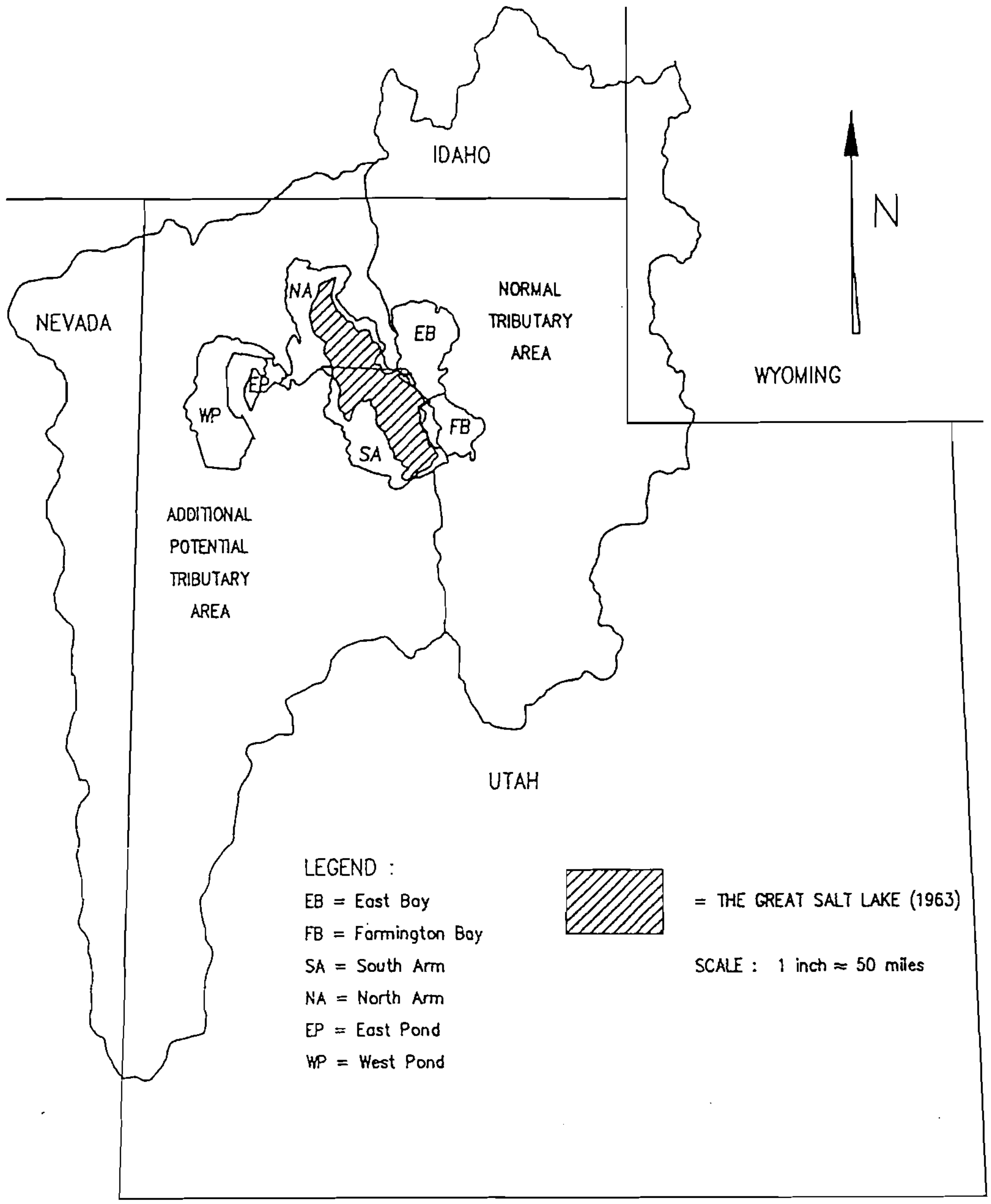

FIGURE 2. Map Showing Great Salt Lake and Tributary Basin.

The rising lake has eliminated waterfowl feeding areas, crippled the mineral extraction industry, forced temporary closures and major construction costs for the vertical relocation of transcontinental railroads and highways, threatened metropolitan waste treatment plants, caused electrical outages, and damaged homes, businesses, farms, and roads. Direct damages have passed $300 million, and the consequences of the ten-foot rise are only a shadow of what would be caused by another ten feet.

HYDROLOGIC FORECASTS

What advice can hydrologists give in this situation? Certainly, we cannot specify a lake level for June 15, 1997, nor even the highest level that will occur by then. The water resources planner deals not in certainty but in contingencies for prudent people to consider. The hydrologist should thus circumscribe ranges of events, within the lead times required to prevent disastrous consequences, at various probability levels so that planners can develop and implement contingency plans. Probabilities are needed for lake

TABLE 1
Physical Data for the Great Salt Lake.

Surface Elevation (feet)[a]	Surface Area (1000 acres)	Storage Volume (1000AF)	Lake Evaporation (1000AF/year)[b]	Mean Salt Concentration (percent)
4191.35-L	587	8,570	1470	27.5
4200	1034	15,390	2910	22.5
4205	1216	21,010	3650	16.3
4211.60-H	1462	29,880	4800	11.4
4216[c]	2050	39,330	6900	8.9
4220-26[d]	3604	66,980	12130	5.9

[a]L = historic low - 1963; H = historic high - 1873 (natural lake area may have been slightly larger at that time).
[b]Evaporation that would occur during an average year equaling the inflow required to maintain the given water surface elevation.
[c]Assuming failures of all existing levees.
[d]Approximated by extrapolation.

TABLE 2
Historic and Recent Data on Great Salt Lake Hydrology.

Historic Data - 1851-1986

	Mean	Standard Deviation
Precipitation	10.70 inches	2.67
Evaporation	48.58 inches	3.42
Streamflow	2,027,000 acre feet	1,001,000

Recent Data - 1982-1986

	Precipitation			Evaporation			Streamflow		Peak Lake
Year	Amount	Nrm Dev	Prob.	Amount	Nrm Dev	Prob.	Amount	Nrm Dev	Level (ft msl)
1982	17.23	2.45	0.007	44.00	-1.34	0.090	2440000	0.41	4200.70
1983	17.79	2.66	0.004	41.85	-1.97	0.024	5304000	3.28	4204.70
1984	16.61	2.21	0.014	44.76	-1.12	0.131	6646000	4.62	4209.25
1985	9.75	-0.36	0.641	47.03	-0.45	0.326	3802000	1.77	4209.95
1986	19.95	3.46	0.0003	45.97	-0.76	0.224	5520000	3.49	4211.80

Note: Probabilities are shown for only precipitation and evaporation as streamflow is not distributed normally.

levels and design quantities (capacities for storm and groundwater pumping, wind wave heights for setting levee freeboards, volumes of water to ~~be~~ evaporated in ponds, etc.).

The approach used in probabilistic forecasting was to 1) define the statistical distributions, cross correlations, and year-to-year relationships found in lake inflows (streamflow and precipitation) and outflow (evaporation), 2) employ stochastic methods to generate a large number of inflow and outflow sets that match those statistics, and 3) ...

into lake level traces over a 50-year planning period. The data on these three traces covered a 50-year period (140 years diminished quality used only in estimating means). A trivariate first order auto-regression model was then used to generate 1000 50-year sequences of three simultaneous annual series of gaged surface inflows, precipitations, and evaporations. The model was validated against the historical distributions and serial and cross correlations.

These sequence sets were then input to a water balance model beginning at the current lake level and incorporating information on

1. The surface area, storage volume, and salt content of the lake by water surface elevation.
2. The effect of salt content on lake evaporation.
3. The variation in precipitation on the lake as rising levels inundate areas with different normal precipitation amounts.
4. Ungaged stream and groundwater inflows estimated with a model calibrated to improve the match of simulated with historical lake levels.

The resulting 1000 lake level sequences gave the probabilistic lake level forecasts shown in Table 3.

TABLE 3.
Probability Distributions of Annual High Levels of the Great Salt Lake Given 1851-1984 Data, 1965 Tributary Land Use, and Assuming No Multi-Year Cyclic Weather Patterns. October 1985 Initial Conditions.

Year	Probabilities of Exceeding			Mean	Probabilities of Dropping Below		
	0.01	0.10	0.25		0.25	0.10	0.01
1986	4211.8	4211.8	4211.8	4211.8	4211.8	4211.8	4211.8
1987	4215.4	4214.9	4214.6	4213.3	4212.5	4212.3	4212.0
1988	4217.7	4216.6	4215.7	4213.7	4211.5	4211.0	4210.3
1990	4220.1	4217.6	4216.8	4213.0	4209.2	4208.2	4206.6
1992	4220.5	4217.8	4216.2	4211.3	4206.4	4205.1	4202.0
1995	4219.7	4215.7	4214.8	4208.4	4202.3	4200.9	4197.0
2000	4217.8	4213.6	4211.4	4204.4	4197.9	4196.2	4192.8
2010	4215.8	4210.9	4207.8	4200.3	4194.1	4192.4	4190.2
2020	4215.2	4210.1	4207.6	4199.3	4193.4	4191.4	4186.7
2030	4214.8	4209.3	4206.6	4199.2	4192.6	4190.6	4185.0
2039	4214.8	4209.0	4206.5	4199.2	4192.9	4190.8	4186.7

PROPERTY MANAGEMENT (COPING)

Property managers facing rising lake levels respond quite differently than those threatened by riverine flooding. Rivers inflict damage over a few hours, and the loss is largely the cost of repair and restoration. Terminal lakes rise over decades, and the loss is largely the cost of self protection activities and values lost because of abandonments. Loss estimation requires projection of property manager decision making in three phases:

Self Protection

Rising groundwater and storm waves may cause damage when the lake is still some distance away. Depending on the property value, a manager decides on wether or not he will invest in pumps to remove groundwater and levees to stop waves. The investment decision ideally weighs returns (or moving costs) against the probability of holding out for a minimum payback period. Hydrologic information is required in making this decision for the design of selected protective systems.

Abandonment

A decision not to invest is essentially one for initial abandonment. At some lake height (above the elevation of highly valued properties), the costs of operating the pumps and maintaining the levees would theoretically force an abandonment decision. However thus far, abandonment has been forced by levee failures. People, who thought themselves protected are suddenly inundated.

Restoration

Some land uses gain little advantage from a lake shore location. Others are prevented from returning (or from being replaced) by floodplain zoning. However, many industrial, commercial, transport, and agricultural uses earn significant income from being near the lake. The managers of such property may legitimately decide the location benefits justify the hydrologic risk. During a subsequent rise the owner would return to the self-protection mode.

ECONOMIC FORECASTS

About $300 million in direct damages (costs of self protection and restoration plus losses during abandonment) have been caused thus far by the rising Great Salt Lake. Given the hydrologic risks and expected management decisions Corps of Engineers' criteria give an expected present worth of additional damage over the next 50 years of $367 million, discounted at 8.625 percent. Undiscounted, the expected additional direct loss is about a billion dollars. Higher-elevation and indirect losses not counted in the Corps reconnaissance could raise the figure to several billion. The total value of the property located between the 1986 high of 4212 and the highest peak in the 1000 generated traces of 4223 is about $3 billion.

The benefits of protection vary greatly among the lake level traces. For example, the probability distribution of the benefits from West Desert pumping (Figure 3) show that most of the "expected present worth" is associated with less than 10 percent of the traces. Benefits would occur with either a rapid rise or a rapid drop; they occur during fluctuating traces where pumping can draw the lake down before a sharp rise. Consequently, Utah has a high probability of putting a lot of money into lake level control and reaping few benefits. Poor criteria for operating the pumping plant and desert ponds or poor land use decisions could significantly increase the damages.

ACTION ALTERNATIVES AND HYDROLOGIC INFORMATION REQUIREMENTS

For present lake level control, the practical alternatives are:

1. Let the property owners cope individually. This approach will cause much greater losses if the Lake continues to rise.
2. Construct shoreline levees for protection of properties clustered in areas with high damage potential.
3. Pump to the West Desert to move higher-elevation storage away from the high damage areas and add evaporative surface.
4. Partition the Lake with island-connecting dikes so that more stable levels can be maintained opposite the most damage-prone areas by having greater fluctuations in more remote areas. The stable bays could also be used for recreation, wildlife, and aesthetic purposes that would add benefits.

These alternatives, listed in the order of progressively increasing cost, are being implemented one by one with the island-connecting dikes still being doubtful. For the long term, coordinated water and land use planning for the basin should consider reservoir and aquifer storage, the consumptive use of fresh water, flow diversions to adjacent basins, and optimal shoreline use. These four present action alternatives have individual requirements for hydrologic information:

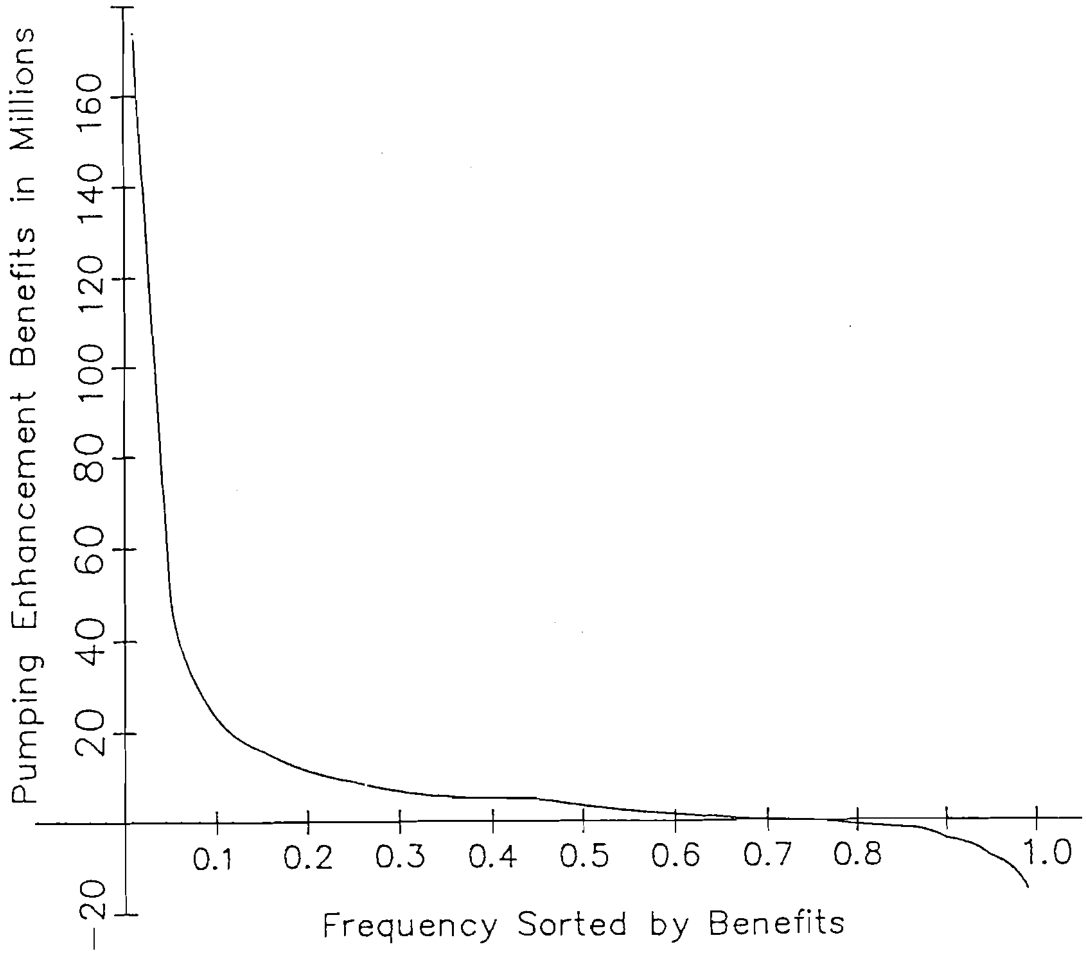

FIGURE 3. Probability Distribution of Pumping Enhancement Benefits.

1. Private Action. Individuals owning property are choosing between investment in self protection or abandonment. They need to know the lake level changes to expect within their planning horizon for comparing present losses with long run profits. For planning and budgeting levee raising, they need to know how high the lake will rise next spring, and would be helped by information on storm waves.

2. Shoreline Levees. Agencies providing levees need a maximum lake level for designing a safe foundation and a distribution of probable levels to make sure that the benefits exceed costs and to select an optimal levee height. Information is also needed on surface runoff and groundwater gradients behind the levee for storm water and drainage designs.

3. Lake Pumping. Hydrologic analysis requires information on how the lake water balance would be affected by pumping patterns. The lake levels at which the pumps are turned on and off and the pond configurations should be optimized. Sufficient lake inflow and outflow scenarios should be used to examine performance in a wide variety of situations.

4. In-Lake Levees. The design of in-lake levees requires subdivision of inflow and evaporation (salinity) estimates among the lake compartments for optimal dimensioning of the pumping and emergency overflow arrangements. Optimal operation of multiple pumps moving water among ponds in a partitioned lake requires dealing with a complex set of interactions among storages and pumping quantities.

NEW HYDROLOGIC FRONTIERS

Hydrologic estimation for terminal lake control has several unique characteristics that will require new lines of research to add hydrologic knowledge for specific applications illustrated from the four roads to disaster listed in the introduction:

1. Continuing Rise. Rapid lake rise could be caused by climatic change, an exogenous event such as a volcanic eruption, or an extreme combination in random processes affecting global weather. In all cases, hydrologic estimation must quantify precipitation, runoff, and evaporation during peak periods when relationships may be quite different than normal. Particularly, a desert basin is characterized by large runoff fluctuations because evapotranspiration takes most runoff in transit except during extreme events. Wet periods add to the mountain runoff and cause more water to reach the terminal lake before evaporating.

2. Levee Failure. Sound prevailing engineering practice, particularly where failure would inundate urban areas, is to design a levee to withstand a rare event. Levee construction at the Great Salt Lake has taken the approach of constructing to a near term lake level so that funds will not be wasted. The philosophy is that if the lake goes higher, the levee can be raised later. The hydrologist thus needs to consider the lead time required to raise a levee in the face of the institutional delays that plague construction projects.

3. Basin Scale Feedback. The evaporation rates used in water balance computations assume that one can extrapolate amounts proportional to area. In fact, evaporation increases humidity, adds downwind precipitation, and reduces downwind evaporation. The lake effect is a positive feedback process adding runoff back to the lake. Partitioning requires that hydrologic studies specify the spatial distributions of surface and groundwater inflow, precipitation, and evaporation. All of these vary considerably over an area the size of the Great Salt Lake.

4. Lake Level Downturn. Obviously, a great deal of money could be saved if we could know when a lake level crest had passed and a downward trend begun. However, before being disappointed that the costly protective measures ~~are~~ may not be needed, we should remember that we are only thankful when we buy insurance against a major medical emergency and remain disgustingly healthy.

CONCLUDING COMMENT

Hydrologic assessment of the control alternatives for the Great Salt Lake has demonstrated the difficulties in infusing recent scientific advances into the political process for budget making. It is a no fault situation. The crisis moves faster than scientists can get on line, and the administrators and politicians resist innovation when so much money is involved. The situation pressures hydrologists to make judgmental guesses and decision makers to choose before finding the people best qualified to do so.

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