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INFORMATION FOR OPERATION OF WATER SUPPLY SYSTEMS

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Introduction

Water requirements increase as more people use more water for domestic purposes. The increase is augmented as technological advances add to the water needs of agriculture and industry. Additional urban landscaping adds further to the demand. Simultaneously, the same forces increase demands for flood control, hydrelectric power, and navigation; and a more urbanized population want more flows preserved for productive natural environments, recreational use, and aesthetic enjoyment.

The response over the years to these growing demands on water resources has been to supply increasing amounts of water and greater levels of development for other purposes by building more projects, larger projects, multipurpose projects, and multiproject systems. The construction and operation of these facilities have changed the flow and water quality regimes of our rivers. Some major river basins are now approaching full utilization of their runoff (U.S. Water Resources Council 1978).

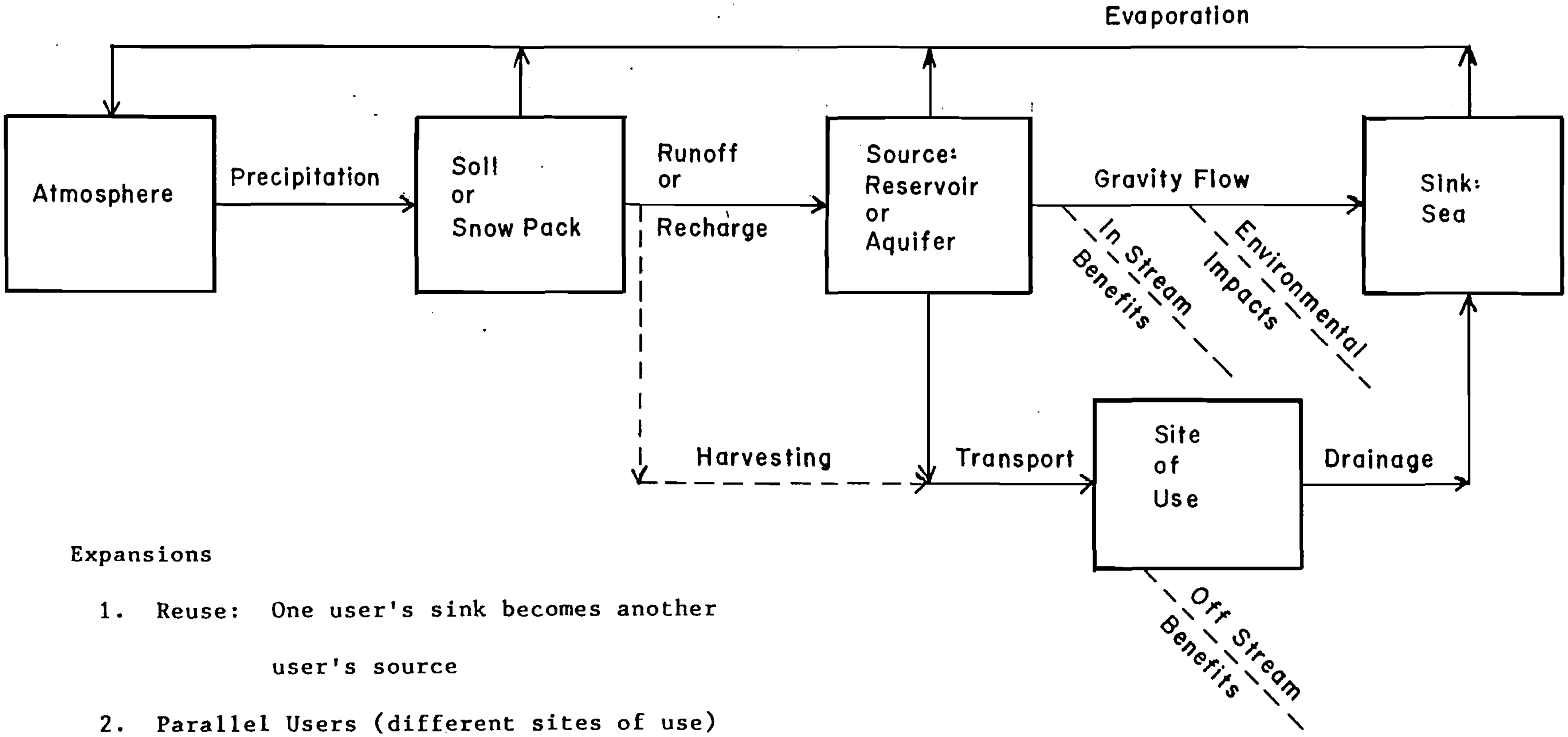
As the opportunities for water project construction are exhausted, the name of the game shifts to systems operation for more precise water delivery when and where it is needed. More rapid and reliable data collection can provide a better information base for determining need. Greater benefits can then be achieved by appplying optimization models on a real time basis and promptly using the results in automated control systems.

Fortunately, the needs for more carefully controlled water resource systems operation come at a time when advances in electronics are offering new surveillance and control technologies. Greater efficiency can be achieved by more rapid measurement and thorough analysis for application of the information that has been used in the past as a basis for systems operation. However, full advantage of the capabilities of the electronic age can only be achieved by gathering information that has previously been impossible or impractical to obtain, developing more comprehensive analytic models, and applying the results with more precise automated control systems.

The purpose of this paper is to stimulate thinking about what can be done. As a starting point, we will gather ideas by diagraming the natural cycle that supplies our water, identifying losses and inefficiencies within it that might be reduced through more effective use of information for operating purposes, and examining existing reservoir operation procedures. The resulting list of potential applications for information and control systems provide direction for refining current automated operating systems. We can end by dreaming about a fully automated system for irrigation water delivery.

The Water Cycle

The Natural Hydrologic Cycle: Water resources development is essentially construction through which some of the water moving through the natural hydrologic cycle is diverted through manmade storage and delivery systems. The four boxes and three arrows shown in the middle of Figure 1 represent this natural cycle. The boxes



Expansions

1. Reuse: One user's sink becomes another user's source
2. Parallel Users (different sites of use)
3. Interbasin Transfers

represent storages and the arrows represent flows. Water begins the cycle stored in the atmosphere. Precipitation falls to earth to be stored in the snowpack or in the soil. Runoff flows downhill to be stored in surface lakes or in underground aquifers. Gravity causes water that is not lost by evapotranspiration in route to continue flowing toward sinks, primarily the ocean, where it remains until returned to the atmosphere by evaporation.

The Water Supply Cycle: Water resources development projects alter the natural cycle. They can harvest runoff or use diversions or wells to intercept flowing or stored water for transportation to points of use. There, irrigation water goes into the soil, and municipal and industrial water is treated, temporarily stored in terminal reservoirs, and used. Some of the water, laden with salts and other waste products, drains on downstream. The transport, use, and drainage processes add new dimensions to hydrologic assessment of system performance by changing the quantity, quality, and timing of the flows.

Expansions to the Diagram: Figure 1 is actually a gross simplification. Three added complexities are particularly important to system operaton:

1. Reuse occurs as the sinks receiving drainage water from upstream users become water sources for others downstream. The three boxes on the right side of Figure 1 may repeat over a number of cycles. System operation requires consideration of the effects of upstream use on the quantity, quality, and timing of water available to downstream users.

2. Parallel users may take water from a common source and deliver it to a common sink. The bottom box may be subdivided into

a number of boxes with one for each user. System operation requires allocation of the available water among the parallel users.

3. Interbasin transfers take water as it flows to the right in the diagram represented by Figure 1 for use or drainage in other catchments. The diagrams for separate basins may be interconnected. System operation requires assessment of the effects on water use in both basins.

Benefits and Impacts: The three diagonal lines on Figure 1 denote the benefits and impacts of water use. Offstream benefits are realized from diverted waters at their point of use. Water uses vary greatly in the benefits derived, the timing and quality of their requirements, and the degree to which water is used consumptively or deteriorated in quality. Instream economic benefits accrue from water quality enhancement, navigation, hydroelectric power generation, recreation, fish and wildlife, and other purposes that essentially leave the water in the stream. Environmental impacts occur as ecological productivity and stream aesthetics are altered.

Losses and Inefficiencies

Effective system operation requires a water delivery among uses and users within uses that maximizes systemwide net benefits without unacceptable environmental impacts. It is achieved by 1) reducing losses in the physical delivery of the diverted water to the users and 2) serving users that realize high levels of benefits.

Efficient physical delivery minimizes losses through a control system that delivers the water when and where it is wanted. The principle of the conservation of mass means that no water is lost in an absolute sense. Losses are operationally defined as water leaving controlled transport systems. Retrieval may be possible by pumping or treatment (desalination) but impractical because it is too costly. Losses occur in four ways:

1. Water returns to the atmosphere through EVAPOTRANSPIRATION.

2. Water SEEPS underground.

3. OPERATIONAL losses as the time pattern of the flows differs from the demand pattern at the point of use, and the water is left to continue downstream without beneficial use.

4. The conveyance of waste discharges, the concentrating effect of evapotranspiration, or leaching as seepage water travels along new paths cause the water QUALITY to deteriorate in ways or degrees that prevent its use for certain purposes. Water quality continues to deteriorate during all the movements shown on Figure 1 except for the natural purifying process of evapotranspiration.

These four physical losses are addressed at two levels of decision making. One relates to the transport arrow and the other to the site-of-use box on Figure 1. The organization supplying the water to the users tries to minimize the delivery losses. The user tries to minimize the same four losses at his point of use. The needed information and control systems differ between these two levels.

Delivery to match greater needs becomes important in managing flow through the total water cycle. Inefficient allocations leave some uses that could achieve a great deal of benefit without water while others receive water but achieve little benefit. These misallocations occur as users are tied to specific water sources (ground or surface), prioritized by factors other than need (junior or senior rights), served within different jurisdictions, or restricted in changing water use practices because of financial obligations for past construction. Exchanges are also affected by the availability of transport facilities. These misallocations continue over time because:

5. Some users save water rights that they do not presently need in order to increase the RELIABILITY of their supply should their demand increase in the future or a drought occur.

6. Some users want a higher QUALITY water than is really necessary for their use.

7. Various INSTITUTIONAL constraints (legal or social) restrict water trades.

Better information provides a basis for protecting water supply reliability and quality through identifying mutally beneficial water exchanges and operating water exchange transport facilities. For example, users with independent supplies may build larger systems in order to avoid losses during period of shortage. However, in doing so, they waste water the rest of the time. This system loss would be avoided by providing facilities and institutional arrangements that permit trades with the other users whose supplies or demands follow different time patterns or who are better able to accommodate to shortage. Similar trades could be arranged when one of the users is more severely affected by poor quality water than another who has a better quality source. Vast potential exists for providing more reliable water supplies through systems operation rather than construction. Tremendous savings have been achieved by advancing intertie technology and systems operation in the electric power industry. The greater transport cost means less potential for savings in water supply systems, but a great deal of benefits can be realized. Once users can be convinced that their needs for greater water supply reliability can be achieved through exchanges, pressures for new construction can be substantially reduced.

Traditional Reservoir Operation

A good starting point for investigating how information surveillance can be combined with advanced control technology to reduce losses and inefficiences in water resources management is to explore opportunities in reservoir operation. The ideal operating guidelines for a multipurpose reservoir maximize net benefits subject to environmental and social constraints (James 1968). However, benefits depend on many factors. The available supply depends on hydrologic conditions in the upstream catchment, and the demands depend on needs in remote use areas. One can visualize a management system that collects data for stochastic estimation of probable supplies and demands, performs an analysis, and signals actions to an automated control system. The state of the art is now shifting from using relatively simple rule curves where the user applied two or three information items in reading a simplified chart (James and Lee 1971, pp. 469-476) to more sophisticated computer-based techniques.

Three operating issues illustrate opportunities:

1. During a flood event, should inflows be stored to reduce current damages or released to provide space should heavy rains continue? Information is needed on projected storm conditions, current runoff rates, reservoir storage characteristics, and downstream flow-damage relationships given the damage that has already

occurred. The control should operate the flood gates to release the indicated flows and do so within the relatively short time frame of the rising limb of a flood hydrograph.

2. During the time of year when flows are relatively high, should water be saved for later beneficial use or should the storage space be kept empty as protection against possible future floods? Information is needed on the benefits of the incremental additional water in alternative uses as opposed to the benefits of incremental storage space in flood damage reduction (James 1966). Projections are needed on runoff volumes, flood probabilities, potential downstream flood damages, and potential water demands. The control should operate the principal spillway releasing water to downstream users.

3. During periods when the reservoir is being drawn down by water supply releases, should the water stored within the reservoir be released for present use or saved for possible worsening drought conditions? Information is needed on present and projected future water needs during the course of the current drought period and for estimating how long the drought period will continue.

A number of other operating issues could be reviewed, but at this point it is more useful to reconsider the second issue more carefully. The principal data needed to divide reservoir storage space between flood control and water supply are the amount of water currently stored in the reservoir (space available for containing floods), the values of the stored water in the various uses to which it is dedicated and in augmenting instream flows, and the value of the flood storage space in reducing flood damage. The measurement of reservoir contents is conceptually straightforward but should be quickly and reliably transmitted to a central reservoir management center.

The more challanging issues are those involved in estimation of the values of the water and the storage space. The value of water depends on the flows expected to enter the reservoir over various future time frames, the expected demands in these same time frames, and the transmission efficiency in water delivery. The value of the flood storage space depends on flood hydrographs expected to enter the reservoir, the hydraulic characterisitcs for routing the reservoir outflow to the damage prone area, and development on the flood plain. Standard practice is to use average information, often by month of the year, in deciding the operating issue. The beauty of an automated surveillance and control system is that it can track specific information on catchment snowpack and soil moisture for use in projecting runoff, monitor the crops being grown in the irrigated area so as to be able to estimate their demands for water, estimate delivery losses, and monitor the flood plains for compliance with flood plain management programs. Not only can this better information be used in operating the reservoir, but it can also be used to improve flood and irrigation water routings by providing better information for model calibration and validation.

Potential Application of Information and Control Systems

Opportunities for making limited available water supplies go futher by applying electronic surveillance and control systems can be assessed by reviewing the storages and flows in Figure 1 in conjunction with the losses and inefficiencies enumerated above. The following are suggestive of a much larger set of possibilities.

1. Atmospheric Storage: Sensing to track moisture-laden air masses or other precipitation determinants (jet streams, atmospheric volcanic debris, etc.) could improve our ability for advanced warning of major floods, but practical methods presently seem remote.

2. Precipitation: Cloud seeding effectiveness has been severely hampered by difficulties in detecting supercooled water and delivering seeding agents where they are most effective (Hill 1983).

3. Soil and Snowpack Storage: Evapotranspiration and seepage losses can be reduced through soil conservation and vegetation management, and these measures can be used more effectively if their employment is monitored. Better control of the flow through the water supply system can be achieved by quick and reliable information on snowpack water content for use in runoff forecasting and on soil moisture for rainfall-runoff prediction.

4. Runoff and Recharge: Natural runoff seldom matches demand timing. If better information were available for forecasting and tracking flow, improved management could be achieved through a) operation of downstream storage reservoirs, b) cropping and other decisions balancing demands with supplies, and c) use of seepage information in managing inflow to recharge areas.

5. Reservoir and Aquifer Storage: Reservoir storage can be accurately tracked through stage measurements, and aquifer storage can be tracked through measurements of the piezometric levels in wells. Both measurements are simple, but voluminous data must be collected. Major opportunities exist for enhancing system operation

through more rapid collection and interpretation of storage data (quantity and quality) from a larger number of reservoirs for system-wide water control and from a very large number of wells to track storage (or pressure) changes in a complicated aquifer system.

6. Controlled Transport: A time lag exists between when water enters a canal or pipeline and when it reaches its point of use. Short term water demands are generally poorly quantified; and, even if they are known, the demand may change, perhaps because of storms or temperature changes, while the water is in transit. Diversions into transport systems are based largely on judgment gained by experience without quantitative analysis because of the difficulties in accumulating data and analyzing current information in the time frame required for real time control. For example, irrigation water is often delivered on fixed rotations because system managers lack the capability to use real time information in allocating water effectively.

7. Site of Use: Farmers observe crop water needs and factor their judgment and personal convenience into irrigation decisions. Remarkable advances in monitoring crop water requirements and in controlled irrigation delivery systems are ushering in a new era.

An automated system comes closer to matching irrigation deliveries with needs, makes irrigation easier, and thus reduces convenience as an excuse for fixed rotation. The opportunities to save water are vastly greater for a municipal user. Urban users water their yards by either rotation or inspection and more often than really needed (Aurestah 1983). Major opportunities also exist for tracking water needs at various demand centers to facilitate trades.

8. Drainage: Often the water discharged is satisfactory for use by someone else. Overall water use efficiency can be increased by monitoring drainage water amounts and quality and transmitting information on availabilities to potential buyers.

9. Sinks: An excellent example of the value of monitoring water sinks exists in the current situation on the Great Salt Lake (James et al. 1984). As the lake rises, managers want short term projections on rise rates, information on how evaporation rates and salt contents vary over the lake surface, and data on risk from storm surge waves that threaten shoreline property.

10. Off Stream Benefits: Agricultural water users can profit from better information on crop water requirements and better controls for delivering water to the crop root zone.

11. Instream Values: We are just beginning to be able to quantify instream economic and environmental values. As we define these values, important indices can be monitored and used to promote desired instream flow values.

12. Expansions: Real time monitoring offers many opportunities to watch water quantity and quality to facilitate water reuse along river systems and to facilitate trades among parallel users or through interbasin transfers. For example, monitoring provides real time information on water needs and availabilities that can be used to revise water allocations among users, particularly during droughts, to increase benefits.

Components of an Automated Operating System

The system for surveillance and control could potentially include:

1. Sensors that detect desired parameters from above (aircraft or satellite) and transform the information into digital code.

2. Sensors that detect desired parameters (water level, precipitation, wind, dissolved oxygen, soil moisture, etc.) on the ground and transform the information into digital code.

3. In order to save power or other costs associated with continuous monitoring, sensors that can be directed from remote locations on when to take measurements.

4. A data collection platform at a location where information gathering is desired and containing a) sensors that measure the desired parameters, b) a power source, for example a 12-volt battery charged by a solar panel in a remote location, and c) a transmitter with an antenna to send the information to a satellite or wire or radio connections.

5. Connections for direct transmission of information (by telephone or radio) from points of measurement to a central control panel.

6. Geostationary Synchronous Environmental Satellites pick up digital signals sent by platform transmitters and relay the data to a receiver. A worldwide network of these satellites is orbiting the earth (Figure 2) and has capacity available for water resources management purposes. Reflections from meteor bursts provide an alternative technology.

7. A receiving dish or downlink that picks up information relayed from the satellites and forwards the data by wire to a computer.

8. A central computer facility that receives information both from direct signals and from the downlink and combines storage and computational capabilities to accumulate, process, and interpret the information and graphical and digital printout to disseminate it to

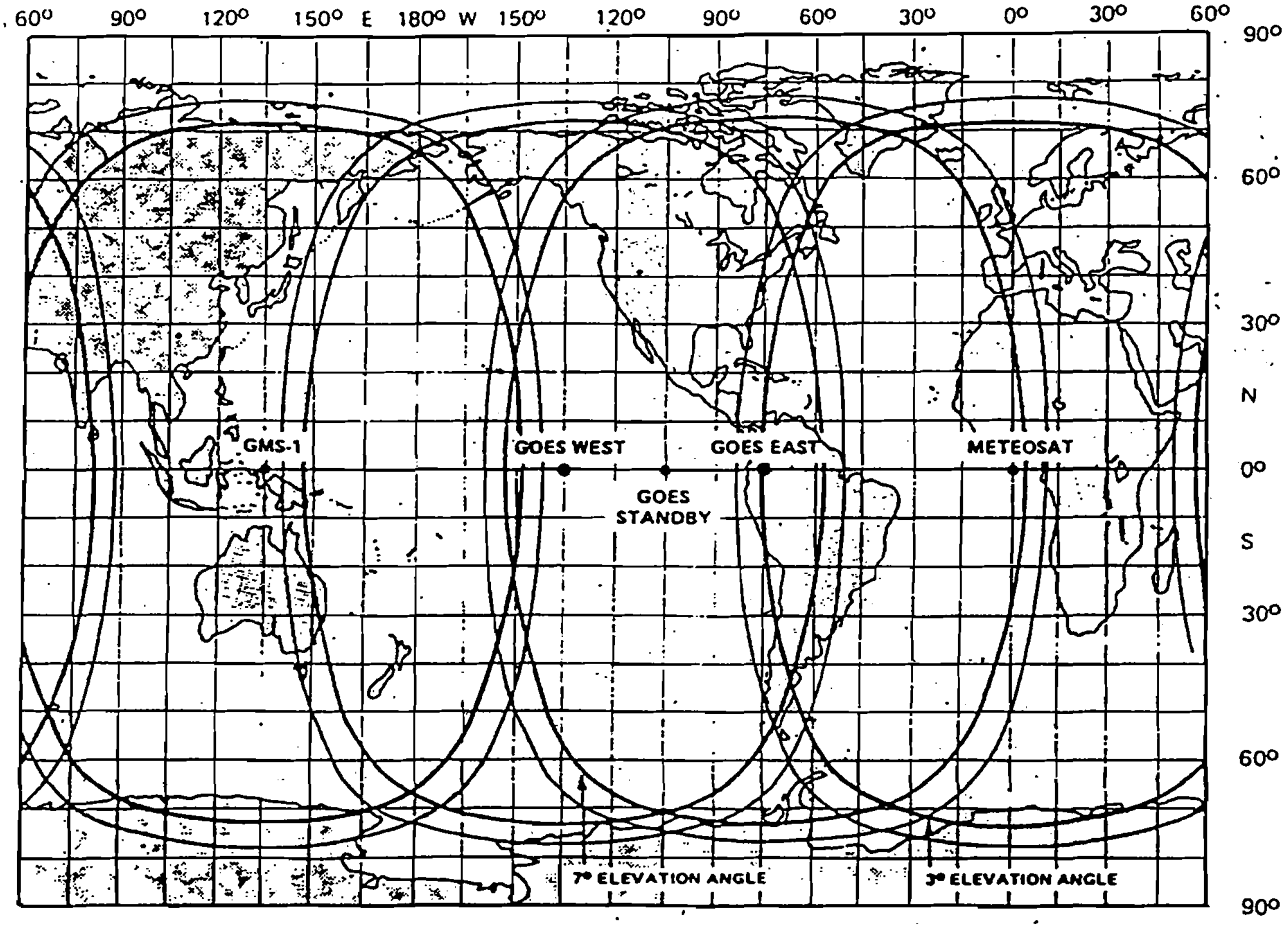


Figure 2. Orbits for GOES satellites.

interested parties. Programming the computational algorithms is a major task in system development.

Some Recent Applications

Remote surveillance and computerized control systems have been introduced for a number of applications. For example:

The U.S. Geological Survey (Shope and Paulson 1980) is operating a large data-collection and teleprocessing network for acquiring and distributing hydrologic data to water users. They found that the benefits are more from better operating performance (flood warning and irrigation water allocation) than from manpower savings. They found satellite data telemetry to be reliable and see expansion of the system as practical real time applications are established.

The U.S. Bureau of Reclamation has implemented a satellite-based, real time data system for irrigation and flood control management in the Upper Snake River Basin. The previous data gathering procedures were associated with substantial delays (6 to 8 weeks were not unusual) from the time the data were collected until they became available for management decisions. The new system provides computer access to information throughout the basin as it is recorded.

Carlson (1979) describes the operation of the Missouri River Reservoir Control Center in Omaha. Centralized computers automatically receive data from main-stem power plants for use in optimizing operation of hydroelectric power generation. Additional information is received from the National Weather Service. Burnash and Twedt (1978) describe how real time data are sent by radio and used in flood forecasting by the California-Nevada River Forecast Center of the National Weather Service.

In 1967, Seattle began a demonstration project to achieve the "ultimate in system storage and control in a combined sewer system through computerized total system management." The resulting "Computer Augmented Treatment and Disposal System" maximizes utilizaton of available storage to reduce the runoff of untreated storm water. As summarized by Lindh (1983), the Chicago Tunnel and Reservoir Plan and the San Francisco stormwater project are other examples.

Belville (1979) describes how satellite imagery can be used to detect intense storms in data sparse areas so that the results can be used in river flood forecasting. Pictures are obtained and analyzed on half-hour intervals from the satellites. Robison (1984) describes how Department of Defense Satellites achieve remarkable surveying accuracy through radio interferometry, a technique that offers a great promise in making the observations needed for hydrologic routing.

Utah State University is working with the State water management agencies to establish a cooperative hydrologic data system (Figure 3). A common facility would be used for research and education applications at the university and for water supply (water rights surveillance) and hazard detection (potential landslides) applications by the state agencies.

The 1983 Colorado Legislature authorized the Water Resources and Power Development Board to evaluate for initiation a satellite monitoring network. The system is envisioned as contributing to water conservation, promoting the beneficial use of water, and improving the economic welfare of the people of the state.

A Remote Sensing Society is being organized out of the University of Reading, England, to coordinate and promote scientific advances that

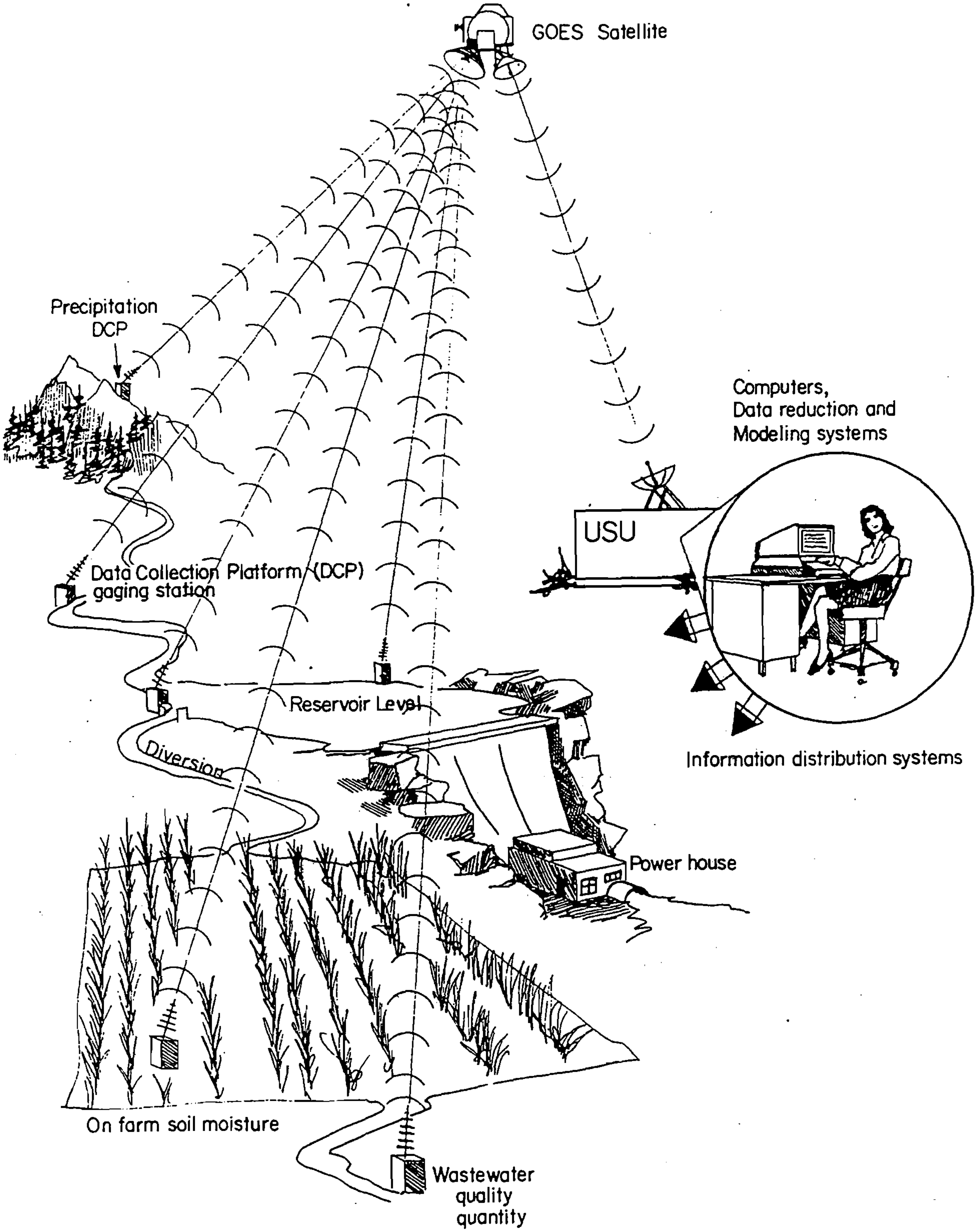


Figure 3. DATA management concept under development at Utah State University.

will contribute to remote sensing and encourage the exchange of information internationally. An International Journal of Remote Sensing is being published.

The Fully Automated Agricultural Ideal

Agricultural water supply systems provide one example of the tremendous potential for greater water use efficiency through automation. A fully automated system for suppling irrigation water can both improve control and facilitate management. One would monitor crop water requirements and release water from storage as needed. Water demands can be sensed from soil moisture measurements, and extrapolated on the basis of average weather conditions (or long term forecasts) to cover the time in transit. Measurements of water in the snowpack and in surface and groundwater storage can be used to assess water availability. Optimization models can be used to allocate deliveries of the available water over time to meet demands and delivery systems can be automated to match optimal schedules. Ultimately, the entire irrigation system can be automated from the reservoir to the field.

Conclusion

Adances in electronic technology offer new information management and remote control capabilities as increasing demands for water resources require more careful operation of the extensive facilities for river basin development buitl in earlier years. This overview revelas diverse opportunities that should be explored and outlines a broad framework for doing so. At the start, we should incorporate supporting basic sciences in the water resources engineering curriculum and develop effective continuing education programs in systems operations. As we expand our capabilities, we will push back the horizons with new applications.

The above pages hardly touch the surface of how electronic surveillance and supporting computer software for real time optimization can improve the coordination of structural and nonstructural measures to facilitate water conservation, reallocate water for greater benefit, increase water delivery efficiency, and ultimately build public confidence in the ability of reliable operation information to reduce needs for new project construction. This outline is offered as a challenge for creative thinking.

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