The Forest Service Barometer Watershed Management Program, A Historic Viewpoint

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During the 1960s, Byron Beattie, Director Division of Watershed Management and Edward Dortignac, Branch Chief of Water Resources of the USDA Forest Service National Office, Washington, DC, conceived a program to bridge the gap between watershed research results and management scale application of science-based principles. The proposal was to select, instrument and calibrate National Forest System watersheds in the range of 50,000 to 150,000 acres (20,200 to 60,700 ha) in each of several hydrologic provinces. Teams of watershed scientists including hydrologists, soil scientists, geologists, and natural resource managers would apply and evaluate science-based management prescriptions. This initiative was the impetus that brought an influx of scientifically trained hydrologists and soil scientists into the Forest Service. This effort included the establishment of a Watershed Systems Development Unit (WSDU) in Berkeley, CA, led by Clyde Shumway. WSDU provided technical support in acquiring state-of-the-art instrumentation and data management programs. An essential part of their effort was the development of computer programs to predict the effects of management activities on water yield and sediment. These were to be applied on the selected "barometer watersheds" as well as in support of the Pacific Southwest Water Plan initiative. Barometer watersheds varied in their success due, in part, to the difficulty of operating sophisticated technology in remote environments. Also, in many cases, coordinating the application of management prescriptions with calibration proved challenging. Regardless of the success of an individual barometer watershed, these efforts on the whole provided the platform for developing critical skills that formed the career foundation for many hydrologists and other earth scientists in the Forest Service.

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Introduction

The U.S. Forest Service Barometer Watershed program was envisioned by Byron Beattie, Director, Division of Watershed Management and Edward J. Dortignac, Chief, Water Resources Branch, USDA Forest Service National Office, Washington, DC. Beattie and Dortignac described the broad goals and objectives of the program in their paper entitled "Using representative watersheds to manage forest and range lands for improved water yield" (Dortignac and Beattie 1965). The essence of the concept was to prototype science developed at plot and small watershed scale and pilot test these findings at a management scale and integrate them with ongoing multiple use practices. The outcomes of watershed prescriptions would be predicted in advance. The post-prescription outcomes would be evaluated and modified as necessary before being more broadly applied in the climatic-physiographic region, referred to as a hydrologic province, represented by the barometer watershed. Dortignac and Beattie (1965) describe the concept as follows:

> The knowledge gained from experimental watersheds of the Forest Service and the data accumulated on other representative watersheds establishes a broad base of knowledge for scientific management of forest and range lands. These findings make it possible to predict hydrologic behavior on a selected watershed for given climatic events, provided the watershed is intensively inventoried and appraised. A reasonably accurate prediction of results is essential

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to management decisions on whether or not to expend the energy and funds needed to implement a watershed prescription.

The Forest Service uses a system of "Representative Watersheds", 50,000 to 150,000 acres [20,200 - 60,700 ha] in size to bridge the gap between research findings and operational management of drainage basins for improving the timing, quantity and quality of water yield from the National Forests. These watersheds register the changes in water yield occasioned by a wide variety of activities in the watershed. From this, the term "Barometer Watersheds" was derived.

The timing for this program seemed opportune in its coincidence with the International Hydrologic Decade and the increased public interest in water yield opportunities (Barr 1956). Also, the Multiple Use Sustained Yield Act of 1960 created a new operating environment that required coordination among activities on the land. The Pacific Southwest Water Plan added additional impetus for water yield studies in watersheds tributary to the Colorado River and in California.

As envisioned by Beattie and Dortignac, a hydrologic province with broadly similar characteristics would be identified, and a representative watershed ranging from 50,000 to 150,000 acres (20,234 to 60,703 hectares) would be selected within this region. For example, the Wasatch Plateaus Province of central Utah was represented by the Straight Canyon Barometer Watershed. After careful survey and characterization of soils, geology, vegetation, climate and hydrology, these watersheds would have integrated multiple use prescriptions developed and applied. The Barometer Watersheds were to have state-of-the-art hydro-meteorological instrumentation installed to evaluate the effects of these integrated prescriptions on water yield characteristics. In addition to the stream gaging stations and recording precipitation gages, a central weather station was included that logged net radiation, dew point, wind at two levels, and temperature. These measurements were supplemented with storage precipitation gages, snow pillows and snow courses.

Beattie and Dortignac prepared a number of additional papers that described the program, as well as describing watershed management concepts that could be applied (Beattie 1962, 1967a, 1967b; Dortignac 1966, 1967). The Glazebrook (1969) paper described progress to that point and indicated that the number of watersheds would not be increased beyond those already established. Glazebrook also stressed that barometer watershed prescriptions would be evaluated in the context of ongoing forest planning efforts. Prescriptions would be considered as alternatives in the plans and implemented if selected in the planning process.

Operations

Essential to this effort was the prediction in advance of the expected outcomes and effects of proposed watershed and other resource prescriptions. Some of the conceptual considerations the watershed scientist needed to evaluate are described in the water balance flow chart in Figure 1. The Watershed Systems Development Unit (WSDU) was established in 1966 to provide support to the field units in installing and maintaining the equipment and to provide the necessary computer programs to translate and manage the data. Of equal importance was the development of computer models to predict the water yield outcomes associated with various prescriptions. A program called "BURP" predicted the water yield outcomes from application of vegetation management prescriptions. The WSDU unit was led by Clyde Shumway and housed at the Pacific Southwest Research Station in Berkeley, CA. Cliff Mansfield provided instrumentation support. By the time the unit was established and operating, a backlog of untranslated data tapes had accumulated at many of the barometer watersheds. A key part of the data management process was a machine to read the punch paper tapes and convert them into computer cards for processing by the computer. This machine was acquired in the late 1960s and experienced considerable down time due to mechanical problems. The machine was housed in Ogden, UT, and all the data from the various watersheds was processed through this machine. Getting the data in proper format and correcting for time errors and missing data required a considerable amount of the barometer hydrologist's time. The computer program development took place on the highly capable computers at the University of California at Berkeley. After development and testing these programs had to be adapted to the less capable computer systems available at the regional office level. Barometer hydrologists pioneered in the use of some of the earliest remote terminal systems available for accessing the central computer systems over phone lines from ranger stations.

The predicted outcomes of the applied prescriptions were to be compared to the measured outcomes. The intent was to refine and adjust the data acquisition and the model until it produced predictions with a reasonable accuracy. Once validated, the model and prescriptions could be applied throughout the hydrologic province, providing managers with predictable outcomes of their planned activities.

These barometer watersheds and the data management and predictions were to be managed on the ground by a

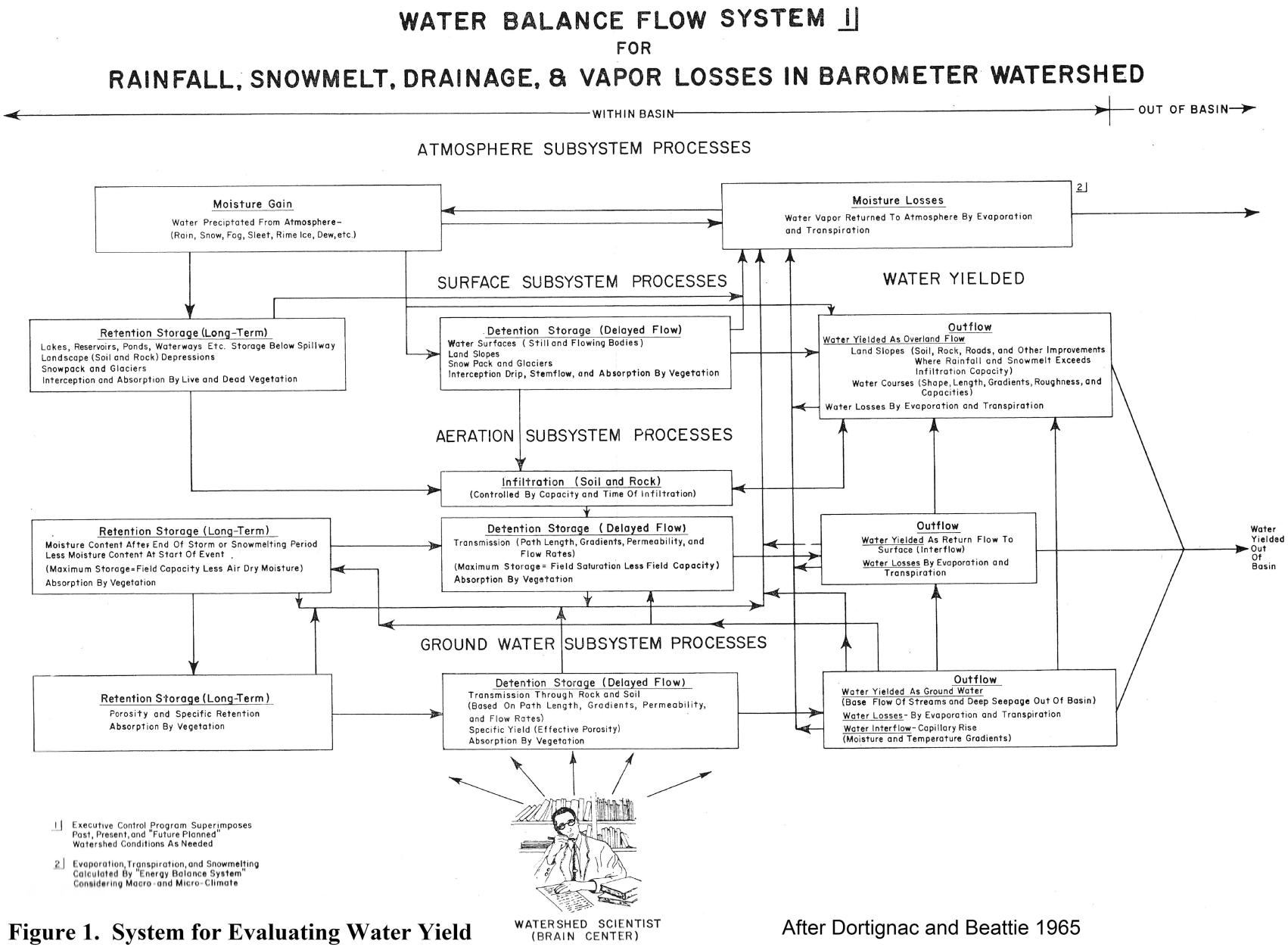

Figure 1. System for Evaluating Water Yield

After Dortignac and Beattie 1965

corps of watershed scientists that included hydrologists, soil scientists and geologists. Large numbers of these specialists were hired beginning in the mid 1960s and extending into the early 1970s. Glazebrook (1969) indicates, for example, that the number of watershed scientists employed by the Forest Service went from 4 in 1961 to 112 in 1969. These people were well trained academically but faced a steep learning curve on the job to cope with myriad daily challenges.

At the outset, 50 provinces were identified that involved National Forest System lands and 50 barometer watersheds were planned. (Delk 1979). By 1969, 23 of the anticipated 50 had been established (Glazebrook 1969). The established barometer watersheds, as of March 1970, are listed in Table 1.

There was wide variation in the level of investment and activity involved in establishing hydro-meteorological instrumentation. This was also true of efforts to characterize the vegetation, soil, climate and geology. For example some watersheds like Lake Fork, East Fork Smiths Fork, Straight Canyon, Encampment River, Black River, Entiat River and Umatilla River were projects where most of the anticipated instrumentation was installed and operating. Other watersheds achieved varying levels of characterization and instrumentation. By 1979, the Delk report identified only 12 watersheds as still operating at some level (Delk 1979). The operating barometer watersheds are identified in bold in Table 1.

Assessment

Based on the analysis and findings of the Delk (1979) report, the National Program emphasis was discontinued. Regions and forests were left to determine what level of emphasis and priority should be given to continuing the Barometer Watershed Program on a local basis. The challenges imposed by the National Environmental Policy Act (NEPA), National Forest Management Act (NFMA), and other acts usually resulted in a choice to shift personnel and funding to these more urgent demands. By the mid

Table 1. Established Barometer Watersheds. These are the 24 barometer watersheds that were established by 1970. **The watersheds identified in bold type are the ones that remained active at the time of the Delk Report in 1979.** *R-1 is the USDA Forest Service Northern Region, R-2 is Rocky Mountain Region, R-3 is Southwestern Region, R-4 is Intermountain Region, R-5 is Pacific Southwest Region, R-6 is Pacific Northwest Region, (R-7 was merged with R-9), R-8 is Southern Region, R-9 is Eastern Region, R-10 is Alaska Region.*

Barometer Name	State	Region	Hydrologic Province
1. Meadow Creek (Horse Cr)	**ID**	**R-1**	**Northern Rocky Mountains (Selway R.)**
2. West Fork Madison River	MT	R-1	Western Rocky Mountains (Madison R.)
3. Lake Creek	**CO**	**R-2**	**Central Rocky Mountains (Arkansas R.)**
4. Encampment River	**WY**	**R-2**	**Sierra Madre (North Platte R.)**
5. Salome	AZ	R-3	Central Arizona (Salt R.)
6. Black River	**AZ**	**R-3**	**Mogollon Rim (Salt R.)**
7. Straight Canyon	**UT**	**R-4**	**Central Utah Plateau (San Rafael R.)**
8. Antimony Creek	**UT**	**R-4**	**Southern Utah Plateau (Colorado R.)**
9. East Fork Smiths Fork	**UT**	**R-4**	**Uinta Mountains (Green R.)**
10. Big Creek	CA	R-5	Southern Sierra Mountains (Kings R.)
11. Upper Santa Ynez River	CA	R-5	South Coastal (Santa Ynez R.)
12. Green River	**WA**	**R-6**	**Northwest Middle Cascades (Puyallup R.)**
13. Entiat River	**WA**	**R-6**	**North East Cascades (Columbia R.)**
14. Umatilla River	**OR**	**R-6**	**Northern Blue Mountains (Columbia R.)**
15. Upper Clackamas River	OR	R-6	West Slope Middle Cascades (Willamette R.)
16. Upper Sauk River	WA	R-6	North West Cascades (Skagit R.)
17. Davidson River	**NC**	**R-8**	**S. Appalachian Mtns. (French Broad R.)**
18. Upper North River	VA	R-8	Valley & Ridge (Potomac R.)
19. Cranberry River	WV	R-9	Appalachian Plateau (Kanawha R.)
20. Hurricane Creek	AR	R-9	Ozark Plateau (White R.)
21. Kawishiwi River	MN	R-9	Laurentian Upland (St. Louis R.)
22. Wild River	NH	R-9	New England (Androscoggin R.)
23. Pine River	MI	R-9	Lower Michigan (Manistee R.)
24. Kadaskan River	**AK**	**R-10**	**Island Southeast (Coastal SE Alaska)**

1980s only a few barometer watersheds struggled on. Most of these had a research study underway making the continued investment more attractive. The program is described in the Forest Service Manual (USDA Forest Service 1965) and the progression in direction can be seen in the revision (USDA Forest Service 1979). The 1965 direction focuses heavily on the technical application of scientific principles and watershed management concepts. By contrast the 1979 direction focuses more on coordination with research efforts and forest planning processes.

The Delk (1979) report provided an insightful assessment of the status of the program. It also described what had been achieved as compared with the original concepts described by Dortignac and Beattie (1965). Delk also provided some views regarding how the program might be adapted to be more relevant and useful in light of current programs and emphasis in the Forest Service. He noted that the barometer program was very successful as a training ground for many of the cadre of hydrologists who currently served the national forests. However, this program was less successful in accomplishing the representative watershed role for a variety of reasons. Drawing on Delk and personal experience the following points may provide useful insights to those charged with developing similar efforts in the future.

Technology. The desired outcomes of the barometer watershed effort relied on cutting edge and yet-to-be-perfected technology. Watershed characterization included stream gaging, precipitation, and climatic measurements. The belief was that current chart recorder technology would produce a backlog of undigested data. To overcome this, punched paper tape technology was selected. This equipment offered the possibility of rapid reduction and compilation of data. The actual situation proved more problematic and the equipment was subject to more mechanical wear and tear, required electrical energy, and thus had a higher maintenance requirement in remote locations. The equipment frequently failed and data was lost until parts could be obtained and installed.

The data tapes required specialized technology to translate the punch paper tapes to computer cards and then to process them through computer programs to produce data records. A considerable quantity of data tapes had been produced before the tape translator reader was acquired. The tape translator was also subject to frequent breakdowns and delays in receiving replacement parts. This added to a further backlog of unresolved data and an accumulation of undetected instrument calibration problems.

The computer programs to compile the data were under development concurrently with the initial data acquisition. These factors all combined to produce a data analysis backlog that was difficult to overcome. Hindsight suggests that using existing proven data recording technology might have produced better results. At least providing the proven technology as a redundant backup to the punched paper tape systems, as was done by the US Geological Survey, would have provided more reliable and continuous data sets. As reliable improved technology becomes available it can be brought on-line.

Coordination. The outcomes of the barometer watershed effort depended on predicting the results of an integrated prescription, then implementing the prescription and testing the actual outcome with the predicted outcome. The time horizon to accomplish this would likely require at least ten years using the paired watershed approach. This would involve five years of calibration followed by five years of post-activity evaluation. The reality was that coordinating timber harvest and other activities with barometer watershed objectives was not achieved for a variety of reasons. These included inability to delay ongoing timber harvest activities, failure of timber markets to develop as planned, fires, and changing environmental requirements.

Scale Issues. Study strategies for dealing with watersheds of 50,000 to 150,000 acres (20,200 to 60,700 ha) were inadequate. While perhaps a realistic management scale, they represent a huge departure from small research watersheds and plot studies. The relative amount of change possible from an activity is limited by scheduling, timing, duration and extent of the treatment relative to the size of the watershed as a whole. In addition, a range of environmental constraints and limitations required by consideration for other resource values effectively reduced the magnitude of the prescribed treatment on runoff. A further consideration is the inherent limitation on the accuracy of stream gages on larger flowing rivers. Taken together, these factors made it unlikely that any anticipated resource use or activity would progress at a rate and magnitude to produce a detectable change over the larger watershed area. The lack of detectable change would make it difficult to validate predictions. Hindsight suggests more focused evaluation of smaller management scale watersheds might have been more effective. Perhaps scaling up from one square mile (2.6 km^2) research watershed results to a ten square mile (26 km^2) watershed application with replication within the larger 50,000 to 150,000-acre (20,200 to 60,700-ha) watershed might have produced measurable changes to evaluate. Another possibility would be the use of nested watersheds. For example, some successful studies at Horse Creek, a tributary of the Meadow Creek Barometer on the Clearwater National Forest, Idaho, and Coon Creek, a tributary of the

Encampment River Barometer on the Medicine Bow National Forest, Wyoming (sub-watersheds within larger barometer watersheds), could provide useful information regarding the type of results that could be achieved when applied in a larger watershed. A study at Battle Flat on the Prescott National Forest, Arizona, did rely on the development of extensive networks of nested stream gages. Unfortunately the studies did not get beyond the calibration stage before being discontinued.

Scientific Skills and Experience. Those few barometers that had higher degrees of success benefited from involvement of experienced forest service research scientists. These, for example, included studies at Horse Creek, Coon Creek, and Entiat, and other locations. Other joint efforts involving pilot demonstration watersheds between National Forest Systems and Research at Beaver Creek on the Coconino National Forest in Arizona are good models of the cooperation needed to have a greater likelihood of successful outcomes.

Adaptability. As Delk (1979) points out, the legal, institutional and external requirements imposed on land managers had changed considerably in the years since the program started. Priorities had shifted. The funding process had changed as well, and the amount of funding available was diminished. The barometer program required a sustained effort over a period exceeding a decade to be successful. Even if the technology and trained personnel had been available at the outset, it is unlikely that the effort could have responded to the changes in funding and priority at the scale that was undertaken. Perhaps a greater emphasis on a few prototypes to demonstrate the concept might have proven more effective. A tangible proof of concept is a powerful advocate for the value of a program. Prototyping also allows discovery of flaws and the opportunity for adjustments to be made before broader applications are implemented. Future programs of this nature must consider how they will adapt to rapidly changing priorities, requirements and funding.

Accomplishments

As Glazebrook (1979) pointed out, even though the original planned effort was blunted, there were a number of successes. For example, the barometer watershed program has provided insight into the hydrologic functioning of large watersheds under different conditions of geology, soils, climate, landforms and vegetation. These areas provided excellent training grounds for forest land managers, soil scientists and hydrologists. They have also provided valuable insights to the public regarding watershed management through show-me trips, media articles and interpretative signs. These areas, in some cases, provided venues for scientific study both by internal research scientists and by external cooperators. Meeting the challenges of managing data and developing predictive programs were the forerunners of current planning and assessment tools used in watershed management and land management planning. The barometer watershed effort also produced new analytical methods for dealing with wildland hydrology issues and improved the ability of the Forest Service to deal with watershed issues. A significant part of this improvement is due to the increase in the number of trained scientific professionals in soils and hydrology fostered by the barometer watershed program.

Summary

As we look to the future, it is clear that land management planning and decision making are advantaged by having facts about the climatic and hydrologic situation. Knowledge of the vegetation, soils and geology, coupled with these data, provides an opportunity to improve our ability to evaluate proposed actions in advance of implementation. This predictive ability offers the opportunity to modify actions or incorporate mitigation as was attempted in "An approach to water resources evaluation of non-point silvicultural sources" (WRENSS) (USDA FS 1980). These water facts are vital to the effectiveness of scientifically trained hydrologists and soil scientists in providing advice to managers. Programs such as the barometer watershed management effort have provided additional insights into how wildlands operate. Continuing to emphasize gathering data at strategic sites and pilot testing research findings on a management scale remain valuable tools in closing the gaps between scientific knowledge and management applications. Closing this gap remains one of the key challenges facing land management agencies in the future. Efforts are continuing to improve the speed with which we bring science to bear on management problems. Care needs to be taken, however, in how we deal with new abilities to acquire data. Technology is improving in its ability to gather data effectively at less cost in remote areas. This improved ability to acquire data places a greater burden on the analyst to wisely choose how to strategically set up the data acquisition network to meet objectives. The data acquisition effort must be operated effectively so that data becomes useful information to help guide management. We must avoid the temptation to acquire data merely because it is easy to do so. Data is of little value if it is just collecting dust in an archive.

Overall, while the barometer watershed program failed to achieve all that it set out to accomplish, the program did provide some valuable insights into the operation of wildland watersheds. Approaches similar to

the barometer program can lead to improved modeling of watershed processes, predicting effects of management prescriptions, and identifying critical variables to be measured. Cooperative efforts between the National Forest System and Research and Development are a key factor in attaining successful outcomes in future efforts of this nature.

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