EXECUTIVE SUMMARY

Sustainable Development & Management of Guam's Groundwater: A Recommended Program

Purpose

The attached White Paper reviews unmet historical recommendations for aquifer management and proposes a locally-based program, requiring modest expansion of WERI/UOG resources, to

(1) track and diagnose evolving groundwater conditions relevant to raw water extraction

(2) maximize production potential while sustainably managing the aquifer

Previous recommendations: 1982 & 1992

1982 Northern Guam Lens Study (NGLS). The $1.2M Northern Guam Lens Study gave a conservative estimate of 59 mgd, and recommended a program "to provide a method of monitoring the changes in the fresh water lens as production capacity approaches sustainable yield". The recommended program has yet to be implemented but remains valid in its essentials. (See attached White Paper.)

1992 NGLS Update. The 1992 update of the NGLS suggested total sustainable yield could be revised to ~80 mgd, but noted "However, the primary task should the drilling of more monitoring wells and collection of data…[and] should be pursued without delay." This has yet to be done.

Sustainable Management of the Northern Guam Lens Aquifer: 2012 and beyond

The Sustainable Management Concept (SMC): The emphasis of the 1982 and 1992 reports on ongoing monitoring and revision of sustainable yield presaged the SMC, which acknowledges not only conditions imposed by nature, but also economic, technological, engineering, and socio-cultural considerations—no single number can be designated as *the* "sustainable limit" to production. Rather,

(1) as production rises, the cost of each increment of new production increases

(2) there are inherent tradeoffs between quantity and quality

(3) there are technological and source alternatives for production

(4) optimal management must address demand as well as supply

(5) external costs and benefits must be internalized to promote quality, equity, and publicly acceptable solutions.

Essential Activities for Sustainable Aquifer Management

To support long-term sustainable development and management of the aquifer, a formal *Aquifer Sustainability Research & Development Program* can be put in place, charged with five basic activities:

(1) Aquifer geology: Ongoing research for deeper and better understanding of aquifer geology, especially conditions that affect production potential and water quality

(2) Aquifer hydrology: Maintain accurate & fine-detail, real-time data on aquifer hydrology.

(3) Aquifer climatology: More definitive and reliable climate-aquifer interaction studies.

(4) Aquifer trends: Time-series analyses of actual trends in key quantities.

(5) Sustainable Management: Integrated assessment of economic, hydrologic and engineering factors to determine and recommend to managers and policy-makers.

Recommended Institutional Structure And Steps

(1) Establish at WERI an ***Aquifer Sustainability Research & Development Section*** ($140,000)

a. Chief Scientist: Senior member of the WERI faculty, already on university salary; no additional funding needed.

b. WERI Staff Hydrologist: MS-level, non-tenure track, annual appointment, currently funded by the Guam Hydrologic Survey; no additional funding needed.

c. PhD-level Research Associate ($80,000/yr): Permanent position, but with 3-yr appointments. New position, funding needed.

d. MS-level Research Associate ($60,000/yr): Permanent position. New position, funding needed.

(2) Establish at UOG an **Aquifer *Sustainable Management Research & Development Team*** ($60,000/yr). Includes hydrologists, economists, management experts, and engineers from UOG, with collaborators from other institutions, local public agencies, and private firms. Would be lead by WERI and prepare its research agenda in consultation with the Technical Advisory Committee. Would also prepare proposals, through WERI, for key projects (see item 3, below).

(3) Establish a **Key Projects Fund** for periodic pivotal aquifer studies that are essential for continued success in growing capacity and preserving water quality Such studies could each cost from $50,000 (for 1-year project) to $250,000 (for a multi-year project). Examples:

a. Update of the Aquifer Basement Map using Latest Seismic/Geophysical Technology (2 years; $200,000 to $250,000)

- Would (1) include the parts of the aquifer (mostly on DoD land) that were not explored in the 1982 study and (2) get more accurate and finer-resolution of the rest of the map.

b. Aquifer Recharge from Thermal Imaging of Coastal Discharge (2-3 years; $200,000 to $250,000)

- New technology allows accurate thermal imaging of freshwater plumes to quantify aquifer discharge (hence recharge) and how it changes seasonally (i.e., between wet and dry seasons) and from wet to dry years. Another example would be a seismic/geophysical study to refine large portions or all of the basement map (as in 1982).

c. Fresh Water Storage and Residence Times from Rain and Groundwater Chemistry (1-2 years; $100,000 to $150,000).

- Geochemical studies in other limestone aquifers have established new and reliable methods for estimating the actual volume of rainwater captured and stored in the freshwater lens under different circumstances, and the time that it takes to transit the aquifer.

(4) **Expand and Upgrade the Current Comprehensive Monitoring Program** (PL 24-161). Includes initial investments, plus periodic expansion and upgrade, and recurring O&M costs:

a. Initial fixed cost: Install new, permanent facility for year-round storage and maintenance of USGS instruments, equipment, workspace, and field vehicle, ideally on UOG campus: ~$120,000

b. Periodic fixed costs: Installation & startup of new observation wells: ~$100,000 each + plan for ongoing expansion and maintenance of system

c. Recurring O&M costs: Annual O&M (USGS thru WERI/USGS agreement under CMP program): $20,000/yr for each monitoring well, of which there should ultimately be about 12-18.

Permanent Personnel	**Funding Status**	**Est. additional Funding Needed**
Chief scientist	UOG salary	$0
WERI Staff Hydrologist	UOG/GHS	$0
Full-time Research Associate-PhD	Unfunded	$80,000
Full-time Research Associate-MS	Unfunded	$60,000
Student Research Assistants	Various sources, e.g., NIWWR 104b, NSF, NOAA, GHS, etc.	$0
Regular Research Projects		
Aquifer Sustainable Management Team	Unfunded	$60,000
total permanent, regular funding needed		**$200,000**
Key Projects (major, one-time or infrequent projects)		$50,000 to $250,000 each
Basement topography geophysics update (2 yr)	Unfunded	
Coastal discharge thermal imaging, resistivity survey (2-3 yr)	Unfunded	
Aquifer natural tracer percolation, storage, residence time survey (3 yr)	Unfunded	
Permanent Data Collection (ongoing instrumentation and archiving)		
Permanent facility for equipment storage & maintenance	Unfunded	$120,000
Salinity profiling well expansion/update (~$100,000 each)	Unfunded	$400,000 to $600,000 total
Recurring (annual) O&M costs (~$20,000 each)	Unfunded	$240,000 to $360,000

Sustainable Development & Management of Guam's Groundwater: A Recommended Program

Purpose

As extraction from the aquifer approaches levels previously identified as "sustainable yield" in past studies, it becomes increasingly important to develop and adopt a modern systematic *Sustainable Management Approach* that mobilizes new technologies and best management practices to achieve optimal production, quality, consumption, and cost. This White Paper reviews the previous sustainable yield studies and their still unmet recommendations for data collection, and proposes a locally-based *Aquifer Sustainability Research & Development Program* that makes best use of local scientific and technical resources to

(1) track and diagnose evolving groundwater conditions relevant to raw water extraction, and

(2) recommend how to maximize the production potential of the aquifer for economically and equitably meeting the fresh water needs of the community

Past Sustainable Yield Studies

1982 Northern Guam Lens Study (NGLS). In the recommendations of the pivotal 3-year, $1.2M Northern Guam Lens Study, which produced a conservative estimate of sustainable yield of 59 mgd, the late John Mink (study director) offered the following prescient advice (CDM, Executive Summary, pp. 3-5). In its essentials, it remains not only as valid as ever, but all the more urgent for having not been implemented in the intervening 30 years. Even though some revisions to the original recommendations may now be feasible and appropriate, they remain the point of departure for any discussion of upgrading to the current monitoring system or implementing sustainable management.

To provide a starting point for planning, Mink's 1982 advice is therefore cited below, verbatim, with footnotes added to clarify key definitions or context, or to highlight new considerations or other relevant points [underline added]:

> *"To refine the estimates of sustainable yield and to provide a method of monitoring the changes in the fresh water lens as production capacity approaches sustainable yield[1], the following steps are recommended in order of greatest importance:*
>
> 1. *Three new permanent raingaging stations should be established in northern Guam to refine the estimates of areal distribution of precipitation. The stations should be located in Ordot, Latte Heights, and Agafa Gumas.[2]*
>
> 2. *To monitor the impacts of future groundwater production, water level measurements should be conducted semi-annually in all production and monitoring wells during the months of April (the end of the dry season) and October (the end of the wet season).[3]*
>
> 3. *Each hydrologic subbasin should have at least one continuous water level recorder[4] located in the basal lens to determine the impact of well production and tides on water levels and fresh water lens configuration.*
>
> 4. *All new data should be compiled bi-annually and the estimate of recharge, production, and sustainable yield for each subbasin should be reevaluated, refined, and updated. This bi-annual re-evaluation will*

[1] Where Mink refers to sustainable yield, he means the estimated sustainable yields that were identified in the NGLS study. Implicit in this statement is that the 1982 estimates were deliberately conservative (which he states explicitly in the Introduction of the full report (page 1-2).
[2] These stations have never been installed. Moreover, it is now recognized that additional rainfall data are also needed in other areas across the aquifer.
[3] In the interim, chloride trends have proven to be a more definitive and cost-effective indicator.
[4] Only 3 of the six subbasins contain observation wells with continuous water-level recorders. The 3 that do not are the 3 three currently slated for development inside DOD property to support the anticipated build-up.

insure that the groundwater resources remains protected from over-development. The reevaluation should be done on and annual basis as the sustainable yield [of the NGLS] is approached or is salt water contamination of wells becomes frequent.[5]

5. *A monitoring well network should be established and expanded to complement the existing exploratory well and the USGS observation wells. At least one monitoring well which fully penetrates the fresh water lens should be established in each major well field within the basal areas of the lends for the purpose of monitoring long-term changes in the position of the fresh water-salt water interface as groundwater production increases and approaches the sustainable yield*[6]*. A major well field is an area where several wells are closely spaced such as exists in Dedeo. Though existing monitoring wells may be adequate for most well field in operation today, new monitoring well should drilled as new fields are constructed.*[7]

6. *Lysimeters or other similar devices should be established at locations in northern Guam so that accurate evapotranspiration data can be obtained*[8]*. Though these types of devices are relatively expensive to construct and maintain, the data will provide more accurate information on the amount of rainfall that infiltrates to the groundwater system, and thus, the amount of recharge that enters the Northern Lens.*[9] *This, in turn, will lead to a better assessment of sustainable yield.*

7. *In areas where little or conflicting data exist on the where the limestone aquifer makes contact with the top of the volcanic formation, further exploratory drilling and/or seismic surveys should be conducted.*[10] *Of particular concern are the northern Dededo Well Field area and the Andersen-Northwest Field areas."*

1992 NGLS Update. In his 1992 update of the NGLS, which had the benefit of new data collected in the intervening decade from the new observation wells installed during the 1982 study, Mink suggested that the original total sustainable yield estimate could be revised upward[11] to about 80 mgd, and

(1) Recommended revising the boundaries of the 1982 "management zones" into larger sectors he called "systems,"

(2) Recommended applying transient computer modeling to help predict lens response to changes in recharge and withdrawal,

(3) Stressed the importance of installing additional observation wells to determine and track the actual response of the lens to changes in recharge and withdrawal,

(4) Offered detailed recommendations for further development of each subbasin (in Chapter 5), and

(5) Re-emphasized the importance of institutionalizing a program of regular, systematic re-evaluations of previous sustainable yield estimates

The 1992 recommendations are summarized below [underline added]:

[5] No institutional arrangements or funding have been provided to institutionalize this activity.
[6] This has not been done; the only fully-penetrating wells in operation are those that were established during the 1982 NGLS and restored to service in 1998, when the Comprehensive Monitoring Program was established by PL 24-161.
[7] This has not been done since 1982, until the construction of AECOM-3, in summer 2010.
[8] This remains very expensive and fraught with technical and practical difficulties. A more cost-effective alternative, which has emerged in the meantime, is to evaluate rainwater mass balance and groundwater residence times using natural geochemical tracers, augmented with artificial dye-trace studies.
[9] In the past two decades, it has become apparent that in addition to gaining a better understanding of infiltration and its relationship to storm properties, it is also important to improve our understanding decadal and longer-term weather patterns, in particular storm and drought distribution and intensities.
[10] Mink assigned this last priority because at the time, the signal product of the $1.2M NGLS was the new map of the basement rock that defines the watersheds of the aquifer, so the need for updates lay in the future. An accurate and precise map of the basement remains the single most important tool for successful exploration and design of new wells. WERI updated the map in 2000, and again in 2011, however update and refinement of the map should be an ongoing, high-priority activity, especially as greater demands are placed on hydrogeologists for new exploration in more challenging locations.
[11] Specifically, he noted (page 1-2, Executive Summary, 1992 Report): "As a consequence [of the study update], it now appears that the sustainable yield of the Northern Lens, *available to civilian development* [italics original], may be as much as 60 million gallons per day." [The 1982 study had estimated 59 mgd for the entire aquifer, including the portions under federal property.]

1. *The system of discrete groundwater management zones presented in the NGLS and currently used to regulate groundwater development should be replaced with the concept of Aquifer Systems used in the report.*[12] *Subsequently, the estimated sustainable yield of the new "Aquifer Systems" should be revised continually in light of data obtained from ongoing well development and monitoring.*

2. *Assuming the adoption and acceptance of the new Aquifer System for management of the groundwater resource, additional sustainable yield over that projected by the NGLS may be developable. [This was followed by some specific recommendations for additional development in specific locations.]*

3. *Redevelopment of existing wells should be considered but must be investigated on a case-specific basis in response to actual conditions resulting from the increased production [in nearby new wells].*

4. *The conclusions [of the 1992 study] strongly indicate that update of the NGLS Aquifer Yield Report" and groundwater management techniques is in order. Such an update would require a breadth of testing, modeling and analysis that is beyond the scope of this contract. However, the primary task should the drilling of more monitoring wells and collection of data [underline added]…[and] should be pursued without delay. Additional study of evapotranspiration rates would also provide interesting data for future updates of sustainable yield.*

Sustainable Management of the Northern Guam Lens Aquifer: 2012 and beyond

The Sustainable Management Concept (SMC): Mink's emphasis in the 1992 recommendations on ongoing monitoring and revision of sustainable yield presage the emerging replacement during the past two decades of the old, simplistic, and ultimately impractical sustainable yield concept with the more sophisticated and practical Sustainable Management Concept (SMC). The SMC recognizes that no single number can be designated as *the* sustainable "limit" to production. Rather, it recognizes that

(1) As production rises and the quality and accessibility of the remaining resources decrease, the cost of each additional increment of new production also increases, that

(2) There are inherent tradeoffs between quantity and quality, to which technical and managerial alternatives can be applied, that

(3) There are technological and source alternatives for production, each with different benefit-cost structures, that

(4) 0ptimal management must address demand (consumption) as well as supply (production), and that

(5) External costs and benefits must be internalized to promote quality, equity, and publicly acceptable solutions

Note that the Sustainable Management Concept proceeds from a broader definition of sustainability, which acknowledges not only prospects and constraints imposed by nature, but also economic factors, technological and engineering alternatives, and socio-cultural considerations in the production and consumption of products from natural resources.

Five (5) Essential Activities Needed for Sustainable Aquifer Management. To ensure long-term sustainable development and management of the aquifer, a formal research and development program should be put in place, and charged with the following activities, which would run concurrently and be coordinated with one another:

[12] Mink acknowledged that the "management zone approach" taken in the 1982 NGLS was obsolete by 1992, in light of improved understanding from new data, and should be replaced. It is now recognized that the 1992 concept is itself obsolete and should be superseded by a Sustainable Management approach (see section __ below).

(1) Aquifer geology: Ongoing research to improve understanding of aquifer geology, including the processes that control production potential and water quality:

   a. As development increases, exploration gets harder, options more limited
   b. As island becomes more urbanized, surface contamination threat increases

(2) Aquifer hydrology: Maintain accurate & fine-detail, real-time data on aquifer hydrology:

   a. Actual recharge to the lens and what affects it, and how it varies over space and time
   b. Actual behaviors of the lens in each sub-basin (e.g., responses to recharge, storms)
   c. Actual salinity trends in each sub-basin, well-field, and well
   d. The relations of these to local geologic features (see #1, above)

(3) Aquifer climatology: More definitive and reliable climate-aquifer interaction studies

   a. Current data to determine what conditions are driven by natural processes
   b. Historical data on climate and recharge (the past is the best guide to the future)

(4) Aquifer trends: Time-series analyses of actual trends in key quantities

   a. To make reliable forecasts of changes in quantity and quality of groundwater
   b. To evaluate accuracy of computer model predictions

(5) Sustainable Management: Assessment of economic, hydrologic and engineering factors to determine and recommend to managers and policy-makers:

   a. The cost-benefit trade-offs between water quantity & quality as production increases
   b. Alternative production technologies & their opportunity costs
   c. Appropriate measures for management of consumption (demand) as well as production (supply)

Recommended Institutional Structure and Steps

Composition and Scope: The following recommendations are meant to reflect the minimum investment required in scientific research capacity to support sustainable management of the aquifer. There are four essential components, which are described in greater detail below: (1) Additional permanent scientific staff at WERI dedicated to hydrogeological research to support sustainable development of the aquifer; (2) An inter-disciplinary team of researchers, centered at UOG to develop appropriate economic models and recommend approaches that integrate best available technologies and management practices for sustainable management of Guam's water resources, including groundwater resources; (3) A permanent fund to support key projects that will be needed to improve scientific understanding and support successful engineering solutions for maximizing capacity and preserving quality; (4) Expansion and upgrade of the system of monitoring wells, rain gages, and other hydrologic data collection stations across the aquifer, to support development of undeveloped areas and more intensive development of already-developed areas.

Relationship to Guam Hydrologic Survey and Comprehensive Monitoring Program. The *Guam Hydrologic Survey Program* (PL 24-247) already provides a starting point for permanent maintenance of the database and essential tools for sustainable aquifer development and management (such as the basement map) but GHS is now under-funded for the new tasks proposed herein. The *Comprehensive Monitoring Program* (PL 24-161) already provides a mechanism for funding the collaborative data-collection program, but has so far relied exclusively on annual allocations from the legislature from the general fund. From an economic point of view, funding should be part of the price paid by the consumers of the product, which includes not only GWA customers but DoD users as well. The latter is particularly germane as much of the necessary expansion of data-collection infrastructure should be installed in DoD portions for the aquifer to support the additional production for the anticipated build-up.

Specific Recommendations—Four (4) Essential Components:

(1) Establish at WERI an ***Aquifer Sustainability Research & Development Section***, with the following new positions and responsibilities, under a designated chief scientist (WERI faculty) and working collaboratively with the WERI staff hydrologist (currently funded by GHS):

a. PhD-level Research Associate ($80,000/yr): Permanent position, but with 3-yr appointments. WERI must acquire at least one more full-time, but temporary (i.e., two to three years at a time) scientific professional, at the PhD level (i.e., "post-doc"), who will be focused exclusively on aquifer-related projects. These will require specialized expertise but will vary from time to time. For example, a specialist in groundwater geochemistry might serve for three years to support a major study of groundwater residence time and mass budget, but be followed by another specialist for a subsequent three-year study to develop a high-resolution groundwater model of the Yigo-Tumon subbasin, using data acquired in the preceding study.

b. MS-level Research Associate ($60,000/yr): Permanent position. WERI must acquire at least one more full-time scientific professional, at the MS level, who will be focused exclusively on routine GHS and sustainability research activities. For example, the person in this position would likely be a graduate of the UOG Environmental Science Program, with knowledge of the local hydrogeology and climate acquired from it. His or her responsibilities would include analyzing and tracking spatial patterns and temporal trends in chloride in Guam's production wells and observation wells, under the supervision of the senior hydrogeologist, and in collaboration with counterparts in GWA and NavFacMar.

c. Graduate and Undergraduate Research Assistants, as appropriate: One or more graduate and/or undergraduate research assistants, funded by any of several sources, may also be assigned to work on aquifer sustainability projects. Such projects may, but need not necessarily, be directly related to thesis work and/or sponsored by GHS funds. Undergraduate research assistants would assist with basic but essential tasks such as data entry, scanning of historical documents, and general field and laboratory assistance.

(2) Establish at UOG an **Aquifer *Sustainable Management Research & Development Team*** ($60,000/yr), responsible for Activity #5, which will require the collaborative multi-disciplinary research by teams including not only groundwater hydrologists, but economists, management experts, and engineers, not only from the university, but also invited collaborating researchers from other institutions and from local public agencies private firms, as well. This team would prepare proposals to be funded from the same source as Recommendation #3, below.

- This effort would be led and coordinated by the chief scientist of the WERI Aquifer R&D Section, based on advice and consultation from the Technical Advisory Committee and WERI's Guam Advisory Council. A five-year research agenda would be maintained, with annual agendas prepared in detail. Sixty-thousand dollars annual funding would provide the means to secure faculty time (typically two to eight weeks per year, through summer salary or small contracts) for collaborative research that would integrate economic, engineering, and management expertise with hydrological scientific expertise. The composition of the team, in terms of expertise and individuals, would vary according the specific tasks taken each year. Projects would focus on innovative research to find and/or develop new economic models for recommending optimum combinations of water-production technologies, engineering and management practices, price structures, conservation measures and incentives. Specific products would include such things as economic models, benefit-cost analyses, engineering feasibility studies, management plans, and aquifer development master plans. These would include "leading-edge" studies using new or emerging theory and innovative approaches, as well as well-tested, "tried-and-true," conventional approaches.

(3) Establish a **Key Projects Fund** for periodic pivotal aquifer studies that are essential for continued success in growing capacity and preserving water quality. There are certain kinds of projects that need not (and cannot) be done on a continuing basis, with routine modest investment, but rather require periodic, large-scale investment for a single effort, which may not need to be repeated for another decade or so, when improved technologies are available, or further progress requires that the previous study be expanded to include previous overlooked or excluded areas, or accomplished in finer detail in previously covered areas. It is also necessary to provide a means for taking advantage of new and emerging tools that were not available for previous studies. Such studies would typically each cost from $50,000 (for 1-year project) to $250,000 (for a multi-year project).

Examples of projects that should be launched beginning in the next 3-to-5 years include:

a. Update of the Aquifer Basement Map using Latest Seismic/Geophysical Technology (2 years; $200,000 to $250,000). Would (1) include the parts of the aquifer (mostly on DoD land) that were not explored in the 1982 study and (2) get more accurate and finer-resolution of the rest of the map.

b. Aquifer Recharge from Thermal Imaging of Coastal Discharge (2-3 years; $200,000 to $250,000). New technology allows accurate thermal imaging of freshwater plumes to quantify aquifer discharge (hence recharge) and how it changes seasonally (i.e., between wet and dry seasons) and from wet to dry years. Another example would be a seismic/geophysical study to refine large portions or all of the basement map (as in 1982).

c. Fresh Water Storage and Residence Times from Rain and Groundwater Chemistry (1-2 years; $100,000 to $150,000). Geochemical studies in other limestone aquifers have established new and reliable methods for estimating the actual volume of rainwater captured and stored in the freshwater lens under different circumstances, and the time that it takes to transit the aquifer.

d. Other candidate projects (typically 1-yr; $50,000 to $100,000) would include localized geophysical borehole studies, electrical resistivity studies, etc., within selected sub-basins or around local well-fields. Would

(4) **Expand and Upgrade the Current Comprehensive Monitoring Program** (PL 24-161). Includes initial investments, plus periodic expansion and upgrade, and recurring O&M costs:

a. Initial fixed cost: Install new, permanent facility for year-round storage and maintenance of USGS instruments, equipment, workspace, and field vehicle, ideally on UOG campus: ~$120,000. For the past 15 years, UOG has provided various ad hoc accommodations, including containers, dormitory space, and space in Dean's Circle housing, for which USGS has paid rent. There is a compelling need, however, particularly if the program is to be expanded, to provide a dedicate facility with proper drainage, air conditioning, storm-resistance, durability, and work space for storing and servicing the instruments, equipment, and field vehicle that support the monitoring program. Since the USGS services facilities on both south and north Guam, placing the facility on the UOG campus would provide a convenient central base of operation. It would also provide easy access to WERI personnel who collaborate with and support the USGS service teams that come to Guam quarterly to service the data-collection stations.

b. Periodic fixed costs: Installation & startup of new observation wells: ~$100,000 each + plan for ongoing expansion and maintenance of system. It is premature to identify precisely how many new observation wells will be required or exactly where they can and should be placed, but it is certain at least four to six will be required to provide coverage for the new well fields planned to support the military build-up, and that at least two to three more should be placed in current GWA well-fields that lack coverage at this time. Thus, over the next five to six years, some six to nine new wells should be installed.

c. Recurring O&M costs: Annual O&M (USGS thru WERI/USGS agreement under CMP program): $20,000/yr for each monitoring well, of which there should ultimately be about 12-15. As noted above, it is premature to say exactly how many new wells will ultimately be needed, and how many current ones may be retired as new and better-placed wells are brought on line, but a reasonable minimum number would two to three in each of the six sub-basins, for some 12-18 wells in the permanent system. More may be required as the aquifer is more intensely developed.

d. WERI maintain a Five-Year Plan for CMP upgrades (including major upgrade in next 3 years to achieve 1982/1992 visions and current needs), with annual updates. It is recommended that WERI would maintain a long-term plan (5-year) in consultation with the Technical Advisory Committee and its USGS co-operators.