Water Planning Tools for Fixed Military Installations

Nancy A. Hanna-Somers, Richard J. Hauer, J. Scott Willett, and John F. Langowski, Jr.

The Installation Water Resources Analysis and Planning System (IWRAPS©), developed initially for the Army, provides installation water engineers and planners with a tool that defensibly provides water requirement forecasts and conservation analysis. IWRAPS© models have also been developed for the Air Force (IWRAPS©-AF) and the Navy and Marine Corps (IWRAPS©-NAV). The models are automated for use within PC-based software systems and forecast seasonally disaggregated water requirements into 21 water-use sectors. Water conservation analysis algorithms in IWRAPS© facilitate the analysis of water conservation efforts associated with various end uses to estimate overall program efficiency. Mobilization water requirements planning can also be accomplished with IWRAPS©. The models developed for the military service branches improve estimating water requirements from conventional per capita extrapolation to a statistical water use method for predicting past and future water needs.

Planning for future installation water requirements and determining the impact of potential water conservation measures can be crucial to mission preparedness. Recent regional water shortages due to drought, competition for limited water resources, water quality issues, an emphasis on water conservation at federal and local levels, Base Realignment and Closure (BRAC), mission changes, and demonstration of beneficial water use support the need for accurate water requirements forecasting

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tools and accounting of water use. Robust methods to predict future water requirements (or the quantity of water needed by an installation) and accounting for historical installation water use to support water rights litigation are now available for military installation planners to assure water shortages do not affect military operations.

Past conventional planning guidance for water requirements at military installations used a per capita extrapolation of an installation's effective population to forecast future needs. The approach based water-use projections on the premise that 150 gallons per capita daily (gpcd) were required for personnel and family members who work and/or live on-station, or 50 gpcd for the nonresident population of civilians and personnel who live off-station.[1] However, this approach fails to account for unique differences among installations due to mission and size. Further, nonresident water use when metered was found to be closer to 17 gpcd. Water use on a per capita basis also varies at installations, ranging from nearly 100 gpcd to more than 1000 gpcd.[2] Deriving reliable population estimates is difficult at many installations due to the mobility of personnel and the absence of reliable records. It also implied that water use is correlated only with population. Attributes known to influence water use such as weather, irrigation, industrial versus domestic use, and water conservation are not considered in a per capita approach.

Accounting of water use is preferably captured through metering of all end uses. Metered water uses would allow a thorough understanding of how and where water is used. However, metering end uses of water at most military installations is very limited. Further, historical records of metered end uses are partial at best. The lack of metered connections and records can be explained by the concept that the military ultimately pays for all the water it produces and a perceived benefit to metering end uses is missing.

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Alternative methods to predict water use are thus important and needed by water engineers and planners. This article presents the development and application of a method that is now available at military installations to estimate installation water requirements. The method can be applied to examine both historical and future water requirements. All military branches are positioned to implement this improved approach to predict water requirements based on building area and other acceptable determinants of water use. The development and application of this approach are also explained.

DEVELOPMENT OF WATER REQUIREMENT FORECASTING TOOLS

Pioneering work at the U.S. Army Corps of Engineers Construction Engineering Research Laboratory produced a water forecasting system for fixed Army installations that estimated water requirements based on the square footage of buildings in three water-using sectors.[3] Water requirements were estimated as a function of the buildings' square footage multiplied by a water-use coefficient in three sectors: community service, military activity, and utility support. For example, water

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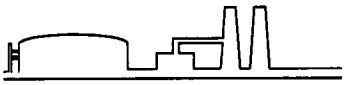
requirements in the community service sector were estimated to be 0.339 gallons used per square footage per day. An underlying premise of this approach was if water use at military installations could be explained by the square footage of buildings, then future water requirements could be estimated based on the planned construction and demolition of buildings. This technique was a vast improvement over the per capita approach, resulting in a reduction of approximately 30 to 85 percent of the variance. However, additional characteristics of water use associated with outdoor water use, weather, climate, and mission were not addressed in the model.[4]



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By the mid-1980s, the Army was becoming increasingly concerned with maintaining an adequate installation water supply. In early 1987, the Army Science Board, by request of the Assistant Secretary of the Army for Research, Development and Acquisition, J.R. Scully, appointed an ad hoc subgroup to study water problems and research needs of Army installations in the western United States. In early 1988, the ad hoc subgroup identified several critical water supply concerns and issues for Army installations as follows:[5]

- no appropriate legal strategy to deal with current and future water rights issues;
- inadequate management and conservation of current resources;
- little planning for the future water needs of the Army;
- existence of barriers in cooperative working relations between Civil Works and Military Construction within the USACE that hinder good water planning;
- inconsistent levels of personnel expertise at different USACE district and division offices;
- Major Commands (MACOMs) and installations; and
- private contractors with vastly different skill and experience levels used for installation studies.

This led to proposed resolutions at a landmark conference, at which the need for state-of-the-art procedures for assessing an installation's water supply, disaggregated uses, water conservation, and contingency plans for disaster situations and mobilization were highlighted.[6] Efforts were undertaken to develop a Water Resources Planning and Management Procedures Guide. The guide was a starting point for effective water resource management and planning. A second study was performed in 1990 to survey Army installations in the continental United States (CONUS) for water-use data and conservation practices and to develop a water-use forecasting model using a building square footage approach similar to work previously conceptualized by Langowski et al.

The new Army model developed by Feather et al. and sponsored by the U.S. Army Corps of Engineers Institute for Water Resources became known as the Installation Water Resources Analysis and Planning System (IWRAPS©).[7] Version 1.0 improved on the efforts of Langowski et al. in the following ways:

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- incorporated seasonality differences;
- increased the number of water-using sectors from 3 to 21;
- accounted for water-use intensity and mission;
- included the accounting of special-purpose water;
- considered water conservation efforts;
- considered contingency plans based on mobilization; and
- utilized actual metered water-use data.

The Army IWRAPS© model was successfully applied and validated through case studies. Those studies addressed future water requirements, drought contingency plans, mobilization, and water rights litigation. The model was also determined to be a state-of-the-art and a methodologically sound procedure for evaluating water demand at Army installations affected by BRAC actions.[8] The software was updated to include an automated linkage to the Real Property Planning and Analysis System (RPLANS) for updating real property inventory libraries residing within the software program.

In 1994, the U.S. Navy requested that a water forecasting model be developed for CONUS Navy and Marine Corps installations.

A similar theory used to construct the Army IWRAPS© model was employed to develop an Air Force model (IWRAPS©-AF) for CONUS installations. The initial version of IWRAPS©-AF was sponsored by the Air Force Civil Engineering Support Agency and completed in 1993 based on water-use characteristics unique to Air Force installations.[9] A more recent version was developed to improve the prediction accuracy of site-specific installations and to enhance the internal library of winter water-use coefficients.

In 1994, the U.S. Navy requested that a water forecasting model be developed for CONUS Navy and Marine Corps installations. The Naval Facilities Engineering Services Center sponsored the research effort. Water-use data collected from Navy and Marine Corps installations were used to develop the Navy model (IWRAPS©-NAV).[10] IWRAPS©-NAV was completed in 1995, used successfully at two case study sites, and is currently being used for water requirements planning and water conservation analysis at Navy installations in Florida and Washington.

The IWRAPS© models' foundation is based on observed military water use. Water-use surveys in each branch were used to characterize installation water use. This, along with other determinants of water-use, was employed in the water requirements models presented below.

IWRAPS© STATISTICAL MODELS

Ideally, the metering of all water end uses would be the method for determining water requirements at military installations. However, metered end uses of water and meter records are scarce, at best, at most military installations. The installation of meters, meter reading, and record keeping are expensive propositions. Thus, alternative methods to estimate water requirements are needed. Extrapolation of water requirements based on a per capita approach is one method. This procedure, as pointed out earlier, only considers population as a driver for water use and alone is not adequate for predicting total installation water use.[11]

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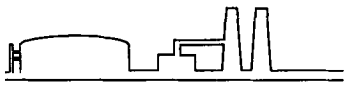
The IWRAPS© general models were designed on the premise that water use is directly related to building use and size and considers seasonal differences (**Exhibit 1**). In theory, winter water use (November through March) is primarily associated with indoor water use, while summer water use (April through October) is a combination of indoor and outdoor water use (e.g., irrigation, swimming pools, and vehicle washing). Seasonal predictions are disaggregated into 21 water-use sectors that range from administration/operation buildings to warehouse facilities (**Exhibit 2**). Twenty-one sectors are used in the models to represent the unique nature of water use in each sector, the buildings' size, and the availability of meters and meter records for buildings. All real property of the installation is allocated to one of the categories based on similarities of water use. For example, water use in a post office is likened to a warehouse building and is included in the warehouse sector. A post office typically has a large area devoted to mail sorting and a small water-use area (e.g., restrooms), similar to many warehouse buildings.

Winter water use is derived from summing the square footage of buildings in a water-use sector and multiplying by a normalized and standardized coefficient of water use in gallons per square foot per day (gpsfpd) in a sector. Water-use coefficients are generated from actual metered water use in each of the 21 sectors and adjusted (normalized) for activity level or intensity of water use. For example, if the actual square footage of a building is twice as much as allowed or required, the intensity of water use is half as much as normal (or expected), thus the coefficient is proportionally adjusted. This allows a coefficient generated at one installation to be used at another. Normalized coefficients are additionally standardized to account for a difference in the required/actual square footage of buildings in a sector at a given installation. Real property records are maintained for military installations and track the actual and required square footage of buildings. For example, the Army uses RPLANS to track real property inventories. A library of these records is included in the software and is easily updated to reflect changes in real property assets.



Special-purpose water relates to water use outside of the 21 water-use sectors or where a square-footage approach is not applicable.

Special-purpose water use is also recognized in the winter model. Special-purpose water relates to water use outside of the 21 water-use sectors or where a square-footage approach is not applicable. Example areas include swimming pools, vehicle wash facilities, research and design buildings, and ship "hotel" facilities. Unaccounted water, common to all water distribution systems, is also a component of the winter model. In sum, the winter model is a function of sectoral water use, special-purpose uses, and unaccounted water.

Summer water use is predicted based on a multiple regression model. The models developed for each service branch are similar in many ways (**Exhibit 3**). For example, they all use mean maximum temperature and mean monthly precipitation in the summer season as surrogate variables for summer irrigation and climate parameters to explain geographic water-use differences. The Air Force and Navy models have parameters that use the installation's mission and installa-

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Exhibit 1. IWRAPS© General Model

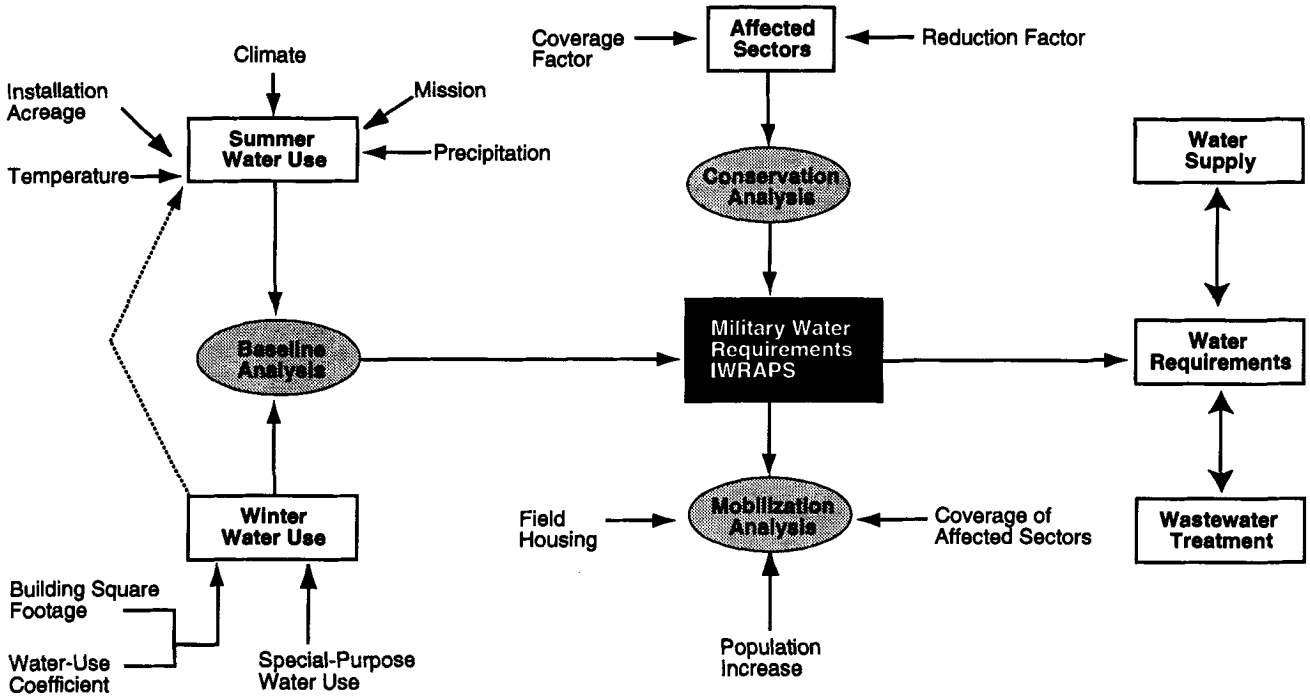

Exhibit 2. Twenty-One Water-Use Sectors

Administration/operations	Bachelor officers' quarters	Banks/credit unions
Barracks	Bowling center	Commissary
Community buildings	Dining	Exchange
Family housing	Guest housing	Gymnasium
Health/dental clinics	Hospital	Laundromat/dry cleaner
Maintenance	Restaurants	Reserves/National Guard
Schools	Service stations	Warehouse

tion-specific calibration coefficients to further explain water use. For example, the existence of a golf course at an installation was found to be uniquely important to summer water use at Navy and Marine Corps

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Exhibit 3. IWRAPS© Summer Water-Use Models

Model Components	Air Force	Army	Navy
Dependent Variable:	QDiff	QRatio	QSummer
Independent Variables:			
Intercept term	Yes	Yes	Yes
Winter water use	No	No	Yes
Mean maximum summer temperature	Yes	Yes	Yes
Mean monthly summer precipitation	Yes	Yes	Yes
Water-use sectoral square footage	Adjusted*	Total	No
Installation acreage	No	Improved**	Total
Köppen's climatic classification			
Mid-latitude steppe (BSK)	Yes	No	No
Subtropical desert (BWH)	No	No	Yes
Humid subtropical (CAF)	Yes	Yes	No
Humid west coast (CB)	Yes	No	Yes
Mediterranean (CS)	Yes	Yes	No
Humid continental cool summer (DAF)	No	Yes	Yes
Humid continental warm summer (DBF)	No	No	Yes
Undifferentiated upland (H)	Yes	No	No
Mission	Yes	No	Yes
Existence of golf course	No	No	Yes
Installation calibration coefficients	Yes	No	Yes
Model R^2	0.84	0.44	0.97

* Adjusted square footage includes all water-use sectors except warehouse and maintenance.
** Improved acreage includes areas that receive annual funding for maintenance.

installations. The variables in the summer model were selected from a collection of variables hypothesized to explain summer water use. During an iterative process, variables that provided the best estimation of water use, using ordinary least-squares regression techniques, were included in the final models. Special-purpose water use and unaccounted water are also common components of summer water use and are included in total seasonal water use.

An important difference among the models is the dependent vari-

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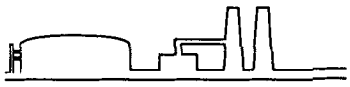
able associated with each model. The Army model uses QRatio, or the ratio of summer to winter water use, as the dependent variable to predict summer water use. QRatio is generated by the model, and summer water use is then calculated from QRatio multiplied by winter water use (i.e., QRatio = Summer water use/Winter water use). The Air Force model uses QDiff as the dependent variable to estimate summer water use. QDiff is derived by the summer model and represents the difference between summer and winter water use. Thus, summer water use at Air Force installations is calculated from the addition of QDiff to winter water estimates. Summer water use in the Navy model is calculated as QSummer. Total summer water use for the Navy is calculated directly within the model.



Water conservation and mobilization modules are integrated with IWRAPS© to allow the development of water requirements planning under both restricted and unrestricted scenarios.

Water conservation and mobilization modules are integrated with IWRAPS© to allow the development of water requirements planning under both restricted and unrestricted scenarios. Estimated water requirements can be incorporated into overall water resource plans at military installations to evaluate the adequacy of water supply and sewage treatment systems (Exhibit 1).

Water conservation analysis in IWRAPS© is facilitated by a conservation module that was incorporated into the software and accounts for savings from conservation efforts. The IWRAPS© conservation algorithm is based on the *I*nstitute for *W*ater *R*esources *M*unicipal *a*nd *I*ndustrial *N*eeds (IWR-MAIN) Version 5.1 model.[12] The effectiveness of an implemented conservation measure depends on the fractional reduction in water use in affected sectors, and the proportion of a sector covered by the measure, expressed as follows:

$$E_{mij} = R_{mi} \bullet C_{mij} \bullet Q_{ij}$$

where: E_{mij} = effectiveness of conservation measure *m* (e.g., plumbing retrofit) for sector *i* (e.g., family housing) in time period *j*, R_{mi} = fractional reduction in use of water for sector *i* as a result of conservation measure *m*, C_{mij} = coverage of measure *m* used in sector *i* at time *j* expressed as a fraction, and Q_{ij} = unrestricted water use in sector *i* at time *j*.

For example, water savings from a plumbing retrofit could be analyzed for a targeted sector such as family housing buildings. A reduction in water use reduces costs associated with water treatment, distribution, heating, and sewage treatment costs. A benefit/cost analysis can be completed based on conservation effort savings and costs to determine the feasibility of the project.

Mobilization contingency planning in IWRAPS© estimates the impact of increased troop strength at an installation. During periods of military crisis, installations that acquire additional personnel must be able to handle the additional water requirements placed on the water supply system. Effective water requirement plans must thus account for full military mobilization at an installation to sustain increased activity. Mobilization forces are accounted for in IWRAPS© under three settings: (1) those housed in existing buildings; (2) personnel housed in newly

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constructed buildings; and (3) troops housed in a field (bivouac) setting.

APPLICATION OF IWRAPS©

Fourteen case studies have been conducted with the IWRAPS© models developed for the military. In addition, utility planners trained in IWRAPS© have successfully developed water requirement forecasts, conservation program evaluations, and mobilization analysis at numerous installations. The models have been highly accurate when compared in backcasts to known seasonal and annual water use (**Exhibit 4**). Calibration of an IWRAPS© model to historical water-use records and accounting for known changes in real property records and mission results in highly reliable water requirement forecasts.

A predictive model such as IWRAPS© is ideal for developing historic and future water requirement justifications tied to administrative and legal actions, BRAC changes at installations, and water conservation analysis mandated by Executive Order 12902 that requires implementation of conservation measures that have less than a ten-year discounted payback period.[13]

The software system has been used to evaluate the impacts from the 1990 BRAC at two California installations, Fort Ord and Travis Air Force Base (AFB). At Fort Ord, the Army IWRAPS© model was used to estimate the water requirements following a significant downsizing operation. Alternatively, the IWRAPS©-AF models were implemented at Travis AFB to determine the impact of adding a large, regional medical center. The outcomes of these two studies exemplify the types of utility planning support these tools offer.

In 1993, an IWRAPS© case study was performed at Fort Ord in northern Monterey County.[14] The installation occupied 28,020 acres and was to be reduced to an operational site of only 1,520 acres. The total potable water use in 1992, the study's base year, was 1.972 million gallons

Exhibit 4. Backcast Accuracy of IWRAPS© Applications

Service Branch	No. of Applications	Seasonal Accuracy of Models (Percentage)[1] Winter	Summer	Annual
Air Force	6	101.8	101.8	101.9
Army	6	99.9	100.4	100.1
Navy	2	104.1	97.5	99.9
Total/Means	14	101.3	100.6	100.8

*Derived from (actual water use/predicted water use) x 100

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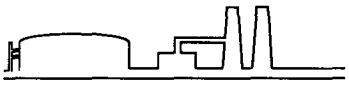
(mgal). Using known information regarding real property assets, temperature, and precipitation for the base year, the IWRAPS© model estimated an annual potable water requirement of 1.878 mgal or 95 percent of the known base year potable production.

Information regarding the anticipated installation reconfiguration was used to forecast water use for 1995, assumed to be the first year the base would be fully operational following the realignment. The software system estimated the potable water requirements for 1995 to be 0.408 mgal, less than one-fourth the annual water requirements of the base year. These reduced requirements for the installation could significantly decrease withdrawals from the Salinas Valley groundwater basin, Fort Ord's sole source of potable water.



Addition and removal of real property assets at Travis AFB were incorporated for modeling future water requirements through the year 2000.

Additional analyses were performed for the reconfigured installation at Fort Ord to determine the impact of four water conservation measures, including (1) a water conservation education program, (2) an infrastructure leak detection program, (3) a plumbing retrofit program throughout the installation (excluding family housing), and (4) low-flow showerheads in the family housing units. The output from the IWRAPS© conservation module estimated that these four measures could save an additional 13.34 percent of annual potable water requirements for the downsized installation.

In contrast to the dramatic size reduction at Fort Ord, the 1990 BRAC activities recommended a mission augmentation for Travis AFB. The base is located in Solano County, 50 miles northeast of San Francisco, and is a well-known staging area for large mobilization actions. The Travis AFB case study was conducted in 1993 using the IWRAPS©-AF forecasting tool and 1992 as the base year.[15] During the study period, Travis AFB utilized on-base wells to service 50 percent of their potable water requirements and purchased the remainder from the surface water supply managed by the City of Vallejo. Installation records for annual potable water production for this period totaled 881.86 mgal. Using known information regarding real property assets, temperature, and precipitation for the base year, the IWRAPS©-AF model estimated an annual potable water requirement of 912.72 mgal or 103.5 percent of the known base year potable production.

Addition and removal of real property assets at Travis AFB were incorporated for modeling future water requirements through the year 2000. Although the total square footage of all sectors in 1995 was less than the total in the base year, the net increase in square footage of larger water-use sectors outweighed the net decrease in other sectors, thus resulting in an IWRAPS©-AF water requirement estimate of 982.04 mgal, an 8-percent increase from the 1992 base year. With the addition of a regional medical center (291,000 square feet) and the construction of BRAC-induced family housing (320,000 square feet) the water requirement estimate for the year 2000 was 1,117.48 mgal, a 14-percent increase over the 1995 estimate. An evaluation of four water conservation measures was conducted, with particular emphasis on reducing the requirement of potable water for installation irrigation. The combined savings of the conservation mea-

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sures were estimated to reduce annual water requirements by 12.9 and 14.6 percent in the forecast years 1995 and 2000, respectively.

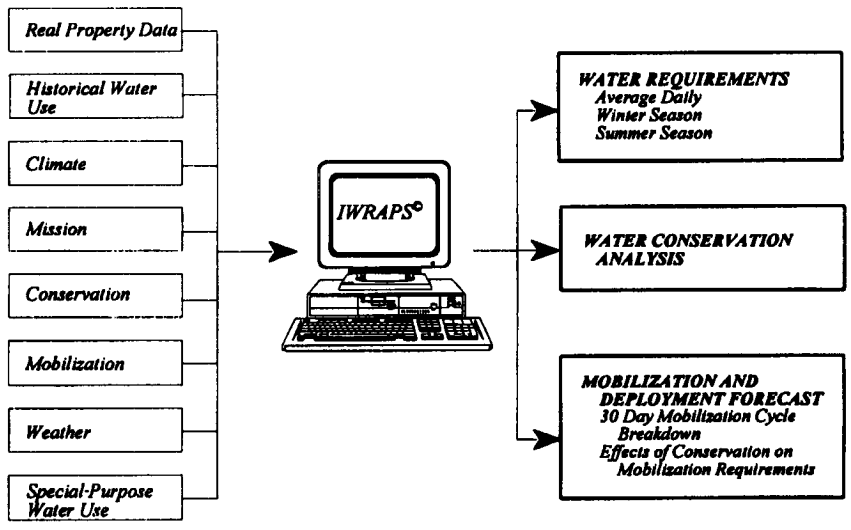
The IWRAPS© models are automated and available through PC-based software programs (**Exhibit 5**).

A minimal amount of data entry (e.g., weather, special-purpose water use, and planned real property changes) is required by the user. Resident real property data and water-use coefficient libraries built into the software expedite the development of water requirements forecasts. The software was designed to run on machines with a 80386 microprocessor or better, to use MS-DOS version 5.0 or greater, and to have a minimum of 640 kilobytes of RAM. An extensive on-line help system is also available to guide the user.

SUMMARY

Water requirements forecasting at military installations has evolved from predicting water use on a per capita basis to a seasonally disaggregated method based on a building square-footage approach using the IWRAPS© models. Since the creation of the Army (IWRAPS©), Air Force (IWRAPS©-AF), and Navy and Marine Corps (IWRAPS©-NAV) models, experience has been gained in the use of water at military installations and methods to predict future water requirements under unrestricted and restricted conditions due to mobilization scenarios, contingency planning, and water conservation analysis. This has put installation planners in an excellent position to develop effective and efficient water requirement plans.

Exhibit 5. IWRAPS© Data Input and Output



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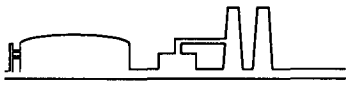
Water conservation program evaluation is a major interest at military installations as a result of federal legislation and local regulations. Federal legislation such as Executive Order 12902 requires water conservation programs be evaluated on a ten-year discounted payback period. The IWRAPS© software expedites the process of evaluating water savings that would result from water conservation efforts. However, a convenient method to assess the monetary benefits and costs of a water conservation program is not currently available.

Research has been proposed to develop a benefit-cost module to be linked to the IWRAPS© software. The module would include a database for cost estimates of potable water production, delivery costs, and wastewater treatment at military installations. Cost estimates combined with savings from conservation efforts would produce economic evaluations such as benefit/cost ratios and discounted payback periods. This should allow utility planners to easily develop an economic analysis of proposed water conservation measures.



IWRAPS© can be used to determine the cost-effective mix of buildings to receive the meters.

As the military services plan to increase the number of water meters at their installations, IWRAPS© can be used to determine the cost-effective mix of buildings to receive the meters. Data collection results can be used to improve the sectoral water-use coefficients across time and lead to a combined library of water-use coefficients, improving the sectoral precision associated with water requirement forecasts. ❖

NOTES

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6. See note 2.

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15. N.A. Hanna-Somers, U.K. Derhgawen, and J.F. Langowski, Jr., "Water Requirements at Travis Air Force Base," Planning and Management Consultants, Ltd., Carbondale, IL, 1993.

[Ed.—For more specific information about the studies cited above, Journal readers can contact Nancy Hanna-Somers at 618-549-2832 or at her Internet address, nans@pmcl.com.]

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