GREEN BOOK
FOR THE
LONG-TERM GROUNDWATER MANAGEMENT PLAN
FOR THE
OWENS VALLEY AND INYO COUNTY

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TABLE OF CONTENTS

INTRODUCTION

The Agreement between the County of Inyo and the City of Los Angeles and its Department of Water and Power on a Long-term Groundwater Management Plan for the Owens Valley and Inyo County (Agreement) in Section I.E provides:

> "The location of each management area, vegetation monitoring site, and each monitoring well; the wells linked to each vegetation monitoring site; the method for locating additional monitoring sites and monitoring wells; the type of monitoring to be conducted at each site; and the standardized procedures for analysis and interpretation of monitoring results, including the determination of available soil water and the amount of soil water required by vegetation, are set forth in a technical document called a 'Green Book.' This 'Green Book' will be attached as a technical appendix to the final long-term Agreement and its accompanying environmental impact report (EIR)."

This document is the "Green Book."

The Green Book consists of five primary sections. The sections are:

I. Vegetation Management

II. Vegetation Inventory and Development of Vegetation Management Maps

III. Vegetation Monitoring

IV. Hydrologic Management

V. Further Studies

Section I on Vegetation Management describes the goals and principles of the Agreement that pertain to management of the vegetation types. This section sets forth the procedures and methods for achieving these goals and principles.

Section II describes the process of compiling the vegetation inventories and the development of the management maps that are to be used in achieving the goals of the Agreement.

Section III describes the techniques and methods to monitor the vegetation and calculate soil-plant water requirements.

Section IV outlines the criteria and procedures to be used in monitoring and evaluating hydrologic data. Also, the section sets forth the procedures for locating and operating the new wells, and the methods of avoiding groundwater mining.

Section V of the Green Book outlines further studies that are being considered to more effectively achieve the goals and principles of the Agreement over the long term or needed to refine monitoring procedures based on new technology.

Section VI, the Appendix, contains various supporting technical vegetation information.

Provisions for revising and updating the Green Book are specified in Section III.E of the Agreement, which states:

> "...modifying the provisions of the 'Green Book' as a result of information gained from ongoing research and cooperative studies or for other reasons, as may be necessary to improve the effectiveness of the monitoring and the evaluation activities."

I. VEGETATION MANAGEMENT

This Green Book section describes methods for achieving the goals and principles for vegetation management of the Agreement. Unless otherwise specified, determinations, decisions, or actions called for in this section will be made by the Technical Group. When reference is made to changes in surface-water management practices, changes will be determined in comparison with past practices since 1970.

A. Management Goals

The overall goal of managing the water resources within Inyo County is to avoid certain described decreases and changes in vegetation and to cause no significant effect on the environment which cannot be acceptably mitigated while providing a reliable supply of water for export to Los Angeles and for use in Inyo County. This means that groundwater pumping and changes in surface water management practices will be managed with the goal of avoiding significant decreases and changes in Owens Valley vegetation from conditions documented in 1984 to 1987, and of avoiding other significant environmental impacts.

For management purposes, the Agreement divides the vegetation of the Owens Valley floor into five management types classified as A, B, C, D, and E. Should it be determined through ongoing monitoring, studies, or analysis, that vegetation is incorrectly classified, it will be reclassified as appropriate. The management goals for Owens Valley vegetation are:

1. <u>Type A Vegetation</u>

   This type, composed of vegetation with a calculated ET rate approximately equal to precipitation, should not be affected by groundwater pumping or by changes in surface water management practices since such vegetation survives on available precipitation

2. <u>Types B, C, and D Vegetation</u>

   The goal is to manage groundwater pumping and surface water management practices so as to avoid causing significant decreases in live vegetation cover, and to avoid causing a significant amount of vegetation now comprising either the Type B, C, or D classification to change to vegetation in a classification type that precedes it alphabetically (for example, Type D changing to either C, B, or A vegetation). In addition, a general goal is to not convert Type D vegetation to cultivated agriculture

3. <u>Type E Vegetation (lands supplied with water)</u>

   These lands will be supplied with water and will be managed to avoid causing significant decreases and changes in vegetation from vegetation conditions that existed on such lands during the 1981/82 runoff year. Also, water will be supplied in an amount sufficient so that the water-related uses of such lands that were made during the 1981/82 runoff year can continue. However, the conversion of cultivated land by the Department or its lessee to other irrigated uses shall not be considered a significant decrease or change. Another primary goal is to avoid significant decreases in recreational uses and wildlife habitats that in the past have been dependent upon water supplied by the Department.

B. Vegetation Monitoring and Management Practices

One means of achieving the management goals for Owens Valley vegetation is an extensive monitoring program developed with the intent of identifying water management-caused problems before impacts occur. Since Owens Valley vegetation varies in its water consumption and sensitivity to soil water changes, different approaches for vegetation monitoring have been tailored to the five vegetation management types. The monitoring procedures are described in detail in Section III.

1. Type A Vegetation

Vegetation of Type A shall, in general, not receive intensive ground measurements, but will be monitored by remote sensing, visual, and other appropriate means.

2. Types B and C Vegetation

Vegetation of management Types B and C generally will be monitored using the procedures for projecting soil-to-plant water balance. Since the species constituting management Types B and C are relatively drought hardy, constant water table/root zone contact is not required for their survival.

a. Groundwater Management

Monitoring within existing well fields will occur at permanently established sites that are linked to pumping wells. Projections of the balance between plant water requirements and soil water availability shall be made to determine whether groundwater pumping may continue or whether pumping should be discontinued. The soil water monitoring sites have been chosen to provide advance warning of plant water deficit in the area of influence from the linked wells. Each monitoring site shall be selected to reflect the combination of dominant vegetation, soil type, or other relevant factors within a management area.

i. Selection of Monitoring Sites and Linkage of These Sites to Wells - Types B and C

Within existing well fields, each well will be tied to a permanent monitoring site. These monitoring sites have been established to permit projecting soil-to-plant water balance, using the monitoring techniques described in Section III and the well turn-on and turn-off provisions described below.

- All existing production wells are currently tied to monitoring sites except wells which are exempt from well turn-off and turn-on provisions, as set forth in Section I.B.2.a.ii.
- For nonexempt wells, monitoring sites have been and will be selected following completion of a hydrologic site assessment described in Section IV. Such hydrologic analyses will be used to determine what land areas lie within the potential zone of influence from either individual wells or well fields. The following activities shall be performed to locate a monitoring site after the hydrologic analyses have been completed:
  - Vegetation and management area maps will be reviewed to determine location and area of vegetation cover that has the potential of being adversely impacted by groundwater pumping.
  - If the vegetation is B or C, soil maps of the region surrounding each pumping well (available from U.S. Soil Conservation Service mapping efforts) will be examined to determine the location and extent of soil types. Vegetation monitoring sites shall then be established to represent the appropriate vegetation type, soil (especially water-holding capacity), topography, and other related factors.

- Each pumping well will be tied to a monitoring site established for projecting soil-to-plant water balance for Types B and C. Table I.A lists the current monitoring sites and the pumping wells to which they are linked.

TABLE 1. A WELLFIELD MONITORING SITES & CONTROL SITES				
MONITORING SITE	YEAR EST.	MONITORING WELL	ASSOCIATED PUMPING WELLS	ASSOCIATED E/M WELL
Wellfields				
Laws:				
Ll	1987	795T	246,247,248,249	
L2	1987	USGS 1	236,239,243,244,365	
L3	1990*		240,241,242	376,377
L4a,4b	1989	2 Piezometers		385,386
L5	#		245	387,388
Bishop Cone:			137,138,140,141,238,235,207,371	
B1	#			
Big Pine:				
BP1	1989	798T	210,352	378,379,389
BP2	1987	799T	220,229,374	375
BP3	1987	567T	222,223,231,232	
BP4	1989	800T	331	
Taboose/Aberdeen:				
TA3	1987	505T	106,110,111,114	
TA4	1989	586T	342,347	
TA5	1989	801T	349	
TA6	1989	803T	109,370	
Thibaut/Sawmill:				
TS1	1987	807T	159	
TS2	1988	806T	155	
TS3	1988	454T	103,104	382
TS4	1989	804T		380,381
Independence/Oak:				
101	1987	809T	77,391	
102	1987	548T	63	
103	#		61,59,65,57,60	383,384
Symmes/Shepherd:				
SS1	1987	USGS 9G	69,392,393	
SS2	1987	646T	74,394,395	
SS3	1987	561T	92,396	99
SS4	1987	811T	75,345	
Bairs/Georges:				
BG2	1989**	812T	76,95,343,348	
Control Sites				
Bishop:				
BC1	1988	USGS 2A “I”		
BC2	1989	796T		
BC3	1989	797T		
Taboose/Aberdeen:				
TAC	1989	802T		
Thibaut/Sawmill:				
TSC1 M	1989	805T		
Independence:				
IC1	1987	USGS 8 “D”		
IC2	1989	801T		

* Established in 1989, but moved in 1990

\# No vegetation monitoring site currently established

** Established in 1987, but moved in 1989

M Formerly TS5

– Vegetation monitoring sites that may experience adverse impacts due to the drawdown of the water table during pumping will be tied to production well(s) with the greatest hydrologic connection (based on such factors as groundwater flow and pumping patterns) and potential for impacting the water table at the monitoring site.

– If hydrologic conditions change such that the linkage of production well(s) to a monitoring site should be changed, the Technical Group may establish new monitoring sites and may re-designate the linkage between wells and monitoring sites as appropriate.

– An existing monitoring site may be relocated if a problem develops with the site, or if the results are inconsistent or of questionable nature, and if relocation is agreed to by the Technical Group. In the event of monitoring site relocation, measurements will be conducted at both the initial and the new sites for a maximum of one year, if possible, unless such monitoring is not required by the Technical Group. If a monitoring site is relocated, the criteria discussed above will be used to select the new site.

ii. Well Turn-on and Turn-off Provisions

Wells will be turned off and turned on as one of the primary methods of achieving the goals of the Agreement. Wells that are not required to be turned off under the provisions below may be turned off if the Technical Group determines that such action would assist in achieving the goals of the Agreement. Any such wells may be turned on by the Technical Group as long as a soil water deficit has not been projected at the monitoring site tied to the well.

- Well Turn-off Provisions

  Soil-to-plant water balance projections for July 1 will be based on the soil water and leaf area monitoring data collected during late June of that year. Transpiration projections for plants at the site shall be made according to the methods presented in Section III.D, with the transpiration curve evaluated for the second one-half of the growing season between DOY=186 and DOY=289 (DOY refers to the day of year as numbered consecutively 1 through 365). Soil water content shall be estimated according to methods presented in Sections III.F and III.G.

  Soil-to-plant water balance projections will be made on October 1 by evaluating the site's transpiration curve through the following growing season as described in Section III.D. The plant-required water will be compared to the plant-available soil water computed by the techniques in Section III.G but adding estimated additional soil water that would be available to plants from precipitation in the following amounts:

  – One-half of the annual average precipitation for the monitoring site shall be added to the computed plant-available soil water. Average annual precipitation has been computed as averages per quadrangle using an isohyetal map (LADWP, 1976). The estimated one-half of precipitation is the amount of water estimated to be available as a long-term, Valley-wide average based on results from vegetation mapping and projection of ET

(Groeneveld, 1988). The amount of precipitation calculated in the soil water projections will be reduced under the following circumstances:

If the actual runoff average for the previous runoff year and the forecasted runoff for the then-current runoff year is less than 70% of average, 40% of the average precipitation for the monitoring site shall be added to the computed plant available soil water.

If the average of the actual runoff for the two previous runoff years and the forecasted runoff for the then-current runoff year is less than 75% of average, 30% of the average precipitation for the monitoring site shall be added to the computed plant-available soil water.

- Pursuant to Section II.C of the Agreement, the Technical Group has designated certain pumping wells which are exempted from linkage to vegetation sites and are not subject to the well turn-off provisions. These exempt wells are specialized cases which are the sole source of supply water for towns, irrigation, and fish hatcheries, or their operation does not affect areas with groundwater-dependent vegetation. The wells exempted are 354, 341, 330, 332, 118, 351, 356, 357, 344, and 346. These exemptions will be reconsidered as appropriate.

- Well Turn-on Provisions
  - Wells that have been turned off under the above provisions may be turned on if soil water in the monitoring site area has recovered to the estimated water needs of the vegetation at the time the wells were turned off.
  - The required soil water level recovery in a monitoring site may be revised if an evaluation of vegetation conditions and other relevant factors indicates such a need.
  - If, subsequent to the time that the well was turned off, the amount of soil water that triggered the turn-off of a well has been revised, the well may be turned on once soil water has recovered to the revised water needs level for the vegetation.
  - If no significant vegetation decrease or change has occurred, and a well has been turned off because of a projected soil water deficit, such a well may be turned on by DWP to supply water to increase the available soil water in the area of the monitoring site.
  - If a significant vegetation decrease and/or change has occurred, and a well has been turned off, the well may be turned on, if necessary, to supply water to avoid additional decreases or changes, and/or to supply water to mitigate such impacts. The following guidelines shall be used by the Technical Group to determine whether such wells should be operated:

    The groundwater extracted will be used only within the area of the well, and no extracted water will be exported from that area; and The Technical Group has determined that the application of water is a necessary part of mitigation for the affected area; and

    Supplying water to the area from a source other than the turned off well is infeasible; and

If it is determined that an alternative supply is necessary and can feasibly be made available to the affected area, it will be made available and the well will be turned off; and

The Technical Group has determined that the need and value of the mitigation is greater than the impacts, if any, that may result from the well operation, and that any such impacts will be avoided or acceptably mitigated; and

Regular operation of the well may be resumed once the mitigation plan for the affected area has been implemented and the Technical Group determines that operation of the well will not result in significant decreases or changes in the vegetation.

b. Surface Water Management - Types B and C

Should water balance calculations project that less soil water will be available in an area of Type B or C vegetation than is required by the vegetation, and should it be determined that the projected soil water deficit is not attributable to groundwater pumping, it will then be determined whether the projected deficit is attributable to changes in surface water management practices. If the projected soil water deficit is attributable to changes in surface water management practices, such action as is feasible and necessary will be taken to avoid significant decreases and changes in the vegetation.

3. Type D Vegetation

Type D vegetation, comprised of riparian and marshland cover, is currently monitored and managed in accordance with procedures described below. This vegetation type tends to be concentrated in areas of streams, swales, water conveyance canals, springs, and flowing wells. Since Type D vegetation is more sensitive to water deficits that Types B or C vegetation, the effectiveness of existing monitoring and management procedures will be evaluated, and appropriate procedures and techniques will be developed to assist in achieving the vegetation management goals and principles of the long-term Agreement.

The Technical Group evaluation will consider the following factors: 1) the need for and the location of additional monitoring sites; 2) site-specific monitoring requirements which may include measurement of water tables, soil moisture, flow rates from springs and flowing wells, water availability at areas of major seeps, vegetation conditions, and visual observations from on-site inspections; 3) the frequency of making on-site visits; 4) the linkage of wells to monitoring sites; 5) the appropriateness of using the “water balance” projections to manage this vegetation type; and 6) well turn-off and turn-on provisions.

During the period that new monitoring procedures are being evaluated, the following procedures and techniques will be employed:

a. Groundwater Management

In addition to the provisions for management of Type B and C vegetation, groundwater pumping will be managed as follows to avoid causing significant decreases or changes in Type D vegetation:

i. The vegetation management maps will be used as a basis for establishing new regional monitoring sites in areas of Type D vegetation where groundwater pumping could potentially affect such vegetation. Visual monitoring at these sites will be conducted as necessary. Generally, monitoring will be by a field visit each month during the growing season, starting with April and ending with October, and by a visit every other month during the other portions of the year. If indications of water deficit stress are observed, a determination will be made whether the cause of the problem is attributable to changes in surface water management practices or to groundwater pumping. This determination will be made in accordance with procedures set forth in Section I.C.

ii. If it is determined that a potentially severe water stress condition that could cause a significant decrease or change in vegetation attributable to groundwater pumping exists, then the wells affecting the area will be turned off unless sufficient water is supplied to the affected area to eliminate the water stress condition.

iii. If no significant vegetation decrease or change has occurred, and a well has been turned off because of projected water stress condition, the well may be turned on by DWP to supply water to eliminate the projected water stress condition in the vegetation in the area of the monitoring site.

iv. If a significant decrease or change in Type D vegetation has occurred and a well has been turned off, the well may be turned on, if necessary, to supply water to avoid additional decreases or changes and/or to supply water to mitigate such impacts. The following guidelines shall be used by the Technical Group to determine whether such wells should be operated:

- The groundwater extracted will be used only within the area of the well and no extracted water will be exported from that area; and
- The Technical Group has determined that the application of water is a necessary part of mitigation for the affected area; and
- Supplying water to the area from a source other than the well that has been turned off is infeasible; and
- If it is determined that an alternative supply is necessary and can feasibly be made available to the affected area, it will be made available, and the well turned off; and
- The Technical Group has determined that the need and value of the mitigation is greater than the impacts, if any, that may result from the well operation, and that any such impacts will be avoided or acceptably mitigated; and
- Regular operation of the well may be resumed once the mitigation plan for the affected area has been implemented and the Technical Group determines that operation of the well will not result in significant decreases or changes in the vegetation.

b. Surface Water Management

If, through field observation and other monitoring, it is determined that changes in surface water management practices could affect or has affected an area of Type D vegetation, the Technical Group shall take such action as is feasible and necessary to prevent significant decreases and changes in the vegetation.

4. <u>Type E Vegetation</u>

a. Water Management

If a significant decrease or change in vegetation conditions from those which existed during the 1981/82 runoff year is projected to occur because of a reduction in the supply of water to the affected lands, and the reduction is not a result of an agreement of the parties pursuant to Section IV.A of the Agreement, if feasible, the supply of water will be immediately increased to avoid such a decrease or change.

The Agreement recognizes that successive dry years could result in insufficient water supply to meet all needs. Section IV.A of the Agreement provides that during periods of water shortages, a program to reduce the amount of irrigation water supply for Los Angeles-owned lands may be implemented if such a program is approved by the County Board of Supervisors and the Department. Factors that.will be considered in determining if such a program is to be implemented include: 1) water use, supply, and conservation in Los Angeles; 2) flows in the Los Angeles Aqueduct System; 3) surface water runoff conditions; 4) level of groundwater extractions; and 5) extent of well turn-offs implemented for purposes of environmental protection.

C. Impact Determination and Mitigation

Among the primary goals of the Agreement are to manage groundwater pumping and surface water management practices as follows: 1) to avoid causing significant decreases in live vegetation cover; 2) to avoid changing a significant amount of vegetation from one classification to a lower (alphabetically) classification; 3) to avoid causing other significant effects on the environment; and 4) in a manner consistent with State and Federal laws pertaining to rare and endangered species. If any of these goals are not achieved, feasible mitigation of the affected area will be implemented. However, mitigation is not considered a primary management tool, but rather a secondary tool that will be employed should impacts occur that are inconsistent with the goals of the Agreement.

This section outlines a procedure for determining whether decreases and/or changes in vegetation or other significant effects on the environment have occurred or are occurring in a given management area. It describes the process the Technical Group will follow to ascertain whether a change is significant, and thus, whether it requires mitigation. It also describes how the Technical Group will develop and implement a mitigation plan and monitoring and reporting program.

1. <u>Determination of Significant Impacts</u>

A significant decrease or change or other significant effect on the environment will be mitigated if it is measurable, attributable to groundwater pumping or surface water management practices, and significant. The Agreement provides that the determination of significance of an impact, and thus, whether it must be mitigated, will be made on a case-by-case basis. The steps in the case-by-case analysis are described below.

a. Determining Measurability

In determining whether a change in vegetation cover or composition is measurable, the Technical Group will consider all relevant factors, including:

i. Comparison of current vegetation cover and composition in the affected area with similar data taken during other time periods, including the 1984-87 vegetation inventory data.

ii. Comparison of vegetation cover and composition at the affected area with vegetation data from one or more control sites located in areas which have similar vegetation, soil, and precipitation conditions.

iii. Comparison of the ratio of recently deceased vegetation to live vegetation in the affected area with other areas not affected by pumping and with similar vegetation cover and composition, soil, and precipitation conditions.

iv. Use of air photo and remote sensing techniques to assist in making comparisons of conditions during different time periods and in mapping the affected area.

v. Comparison of data from randomly selected transects with similar data taken during other time periods, including the 1984-87 vegetation inventory data. This method will be employed in areas where monitoring site data does not exist, or where data covers an insufficient time period. Such transects will be performed as described in Box I.C.1.a.ii.

A determination of measurability will be made if any of the relevant factors considered indicate even a small documentable change in vegetation cover or composition has occurred.

BOX I.C.I.a.ii

TRANSECTS FOR MONITORING VEGETATION RESPONSE TO PUMPING

Vegetation transects are included within the Green Book to serve two purposes: 1) to estimate transpiration from a monitoring site, and 2) for use in determining whether vegetation has decreased or changed significantly from the previous cover.

(1) Detailed measurements of leaf area index shall be made at each of the monitoring sites using the techniques described in Section III.C. These measurements will be used to estimate evapotranspiration from the vegetation at the monitoring site for comparison to available soil water and, ultimately, to project plant-soil water balance and the need for water table recovery.

(2) Vegetation transects shall also be used in cases Of suspected vegetation changes due to groundwater pumping. However, rather than using the intensive sampling technique of Section III.D for calculating evapotranspiration, plant cover shall be measured by the line-point technique described below.

During the 1984-87 inventory, each parcel was sampled with at least five line-point transects of 100 feet in length, with sampling points at one-foot intervals, providing a two-dimensional representation of vegetation within the parcel. At each one-foot marker, the first contact with the uppermost layer of live plant cover was recorded. Cover and species composition were calculated from all sampling points along the transect.

The 1984-87 inventory shall be used as a “baseline” to determine whether vegetation cover and/or species composition has changed. This inventory is the only one of sufficient accuracy to permit comparison. Future line-point transects should be performed in a similar manner as the initial inventory to determine whether vegetation has change, but the technique may be modified to permit detailed statistical comparison by randomly selected transects. Statistical analysis will be used to determine the measurability (statistical significance) of vegetation changes from the 1984-87 inventory maps.

b. Determining Attributability

Once it has been determined that there has been a measurable vegetation decrease or change, it must be determined whether the impact is attributable to groundwater pumping or to changes in surface water management practices.

A determination of whether the impact is attributable to groundwater pumping or changes in surface water management practices will be based on evaluation and consideration of relevant factors, which may include:

i. Recent and historic water table changes and response to pumping as measured at the monitoring site(s) closest to the affected area.

ii. Comparison of soil water, depth to water, and degree of vegetation decrease or change at the affected area and at the control site(s) determined to have similar soil type and vegetation composition and cover.

iii. Comparison of water table depths in the affected area with water table depths in the general region with soils, vegetation cover, and vegetation composition comparable to the affected site. New shallow piezometers may be installed and monitored, if necessary, to obtain relevant water table data.

iv. Rainfall differences that may exist between the control site(s) and the affected area.

v. Evaluation of the extent to which other factors unrelated to the effects of groundwater pumping may have contributed to the vegetation change or decrease. Such factors include drought, wet/dry climatic cycles, flooding, fungal blight, range management practices, wildfire, and off-road vehicles.

vi. Change in soil water within the root zone caused by a pumping-induced change in the water table.

vii. Review of surface water operations to determine if changes from past practices contributed to vegetation changes.

viii. A decrease in flow from a spring or flowing well.

If a decrease in flow from a spring or flowing well occurs, the Technical Group shall determine whether the decrease corresponds to changes in groundwater pumping and runoff. If, on the basis of qualitatively evaluating the data, it appears that the decreased flow corresponds with increased pumping and decreased runoff, the Technical Group shall conduct a quantitative analysis of the data, using one or both of the methods described below, or any other method developed by the Technical Group:

- The Technical Group shall perform a regression analysis of the relevant groundwater level, spring flow, runoff/recharge, and pumping data associated with the site (an example of applying this technique is found in the Technical Group's analysis of the water flow decrease at Reinhackel Spring).
- The Technical Group shall use the groundwater model of the area in question as a supplement to the regression analysis, or as a substitute for the regression analysis if the data are inadequate to develop a regression model. The model would be applied by evaluating groundwater level and spring flow changes in the area under the relevant runoff/recharge conditions that existed under pumping and nonpumping scenarios. For example, the runoff/recharge conditions that existed during the period that the suspected impact occurred would be quantified and entered into the model. The pumping that occurred at that time would also be entered. Results of this run would be compared to a run with the identical runoff/recharge conditions and no pumping. Evaluation of the results would include an analysis of the difference in water levels and/or spring flow in the area to determine if the change that is calculated by the model is sufficient to conclude a pumping-related impact, given the assumptions and limitations of the model.

c. Determining Degree of Significance

Following a determination that there has been a measurable decrease in vegetation cover, and that the decrease or change was attributable to either groundwater pumping or surface water management practices, the following analysis shall be conducted to determine whether the measurable decrease or change is significant. Each of the following factors shall be evaluated and a determination made as to whether or not the impact is significant:

i. The size, location, and use of the area that has been affected.

ii. The degree of the decrease, change or effect within the affected area.

iii. The permanency of the decrease, change, or effect.

iv. Whether the decrease, change, or effect causes a violation of air quality standards.

v. The cumulative effect of the-impact when judged in relation to all such areas of the Owens Valley.

vi. The value of existing enhancement and mitigation projects addressing the environmental consequences of similar impacts.

vii. The impact, if any, on rare or endangered species and on other vegetation of concern.

viii. Whether the decrease, change, or effect affects human health.

d. Determining Significance of Other Effects on the Environment

Any other impacts, including decreases in recreational opportunities and decreases in wildlife habitats, shall be examined by the Technical Group in a similar manner to the procedures set forth above or by other appropriate procedures to determine whether a significant effect on the environment has occurred that is attributable to groundwater pumping or changes in surface water management practices.

2. Development and Implementation of a Mitigation Plan

If it is established that there has been a significant decrease in live vegetation cover, or a significant amount of vegetation has changed from one vegetation classification to a lower classification, or any other significant effect on the environment has occurred, then any such significant impact will be mitigated as soon as a reasonable and feasible mitigation plan is developed. The Technical Group is responsible for developing a mitigation plan for the affected area, and the Department will commence implementation of the plan within 12 months after the significant impact has been established. A written mitigation plan will be prepared by the Technical Group and submitted to the Standing Committee during this 12-month period; however, the Technical Group is not precluded from implementing any necessary interim mitigation measures during this period.

a. In developing a mitigation plan, the Technical Group shall first establish a goal for the plan in conformance with the goals and principles of the Agreement. Thus, if there has been a significant decrease in live perennial vegetation cover or a change in a significant amount of vegetation from one classification to another, a primary goal of the plan would be to avoid causing further decreases or changes.

Generally, if there has been a significant decrease in vegetation live cover, the preferred goal of the plan would be to restore the same type of perennial vegetation cover in the affected area; and, if there has been a significant change in vegetation type, the preferred goal of the plan would be to restore vegetation to a vegetation community that falls within the type classification depicted on the vegetation management map. If any other significant effect on the environment occurs, the goal of the plan would be to reduce the impact to a level that is no longer significant.

Generally, compensatory mitigation (compensating for an impact to the environment by improving or enhancing an area located away from the affect area) would not be a preferred goal of a mitigation plan.

b. In selecting the means of achieving the goals of the mitigation plan, the Technical Group will consider the feasible alternatives. When it is determined that the expertise of a consultant would be beneficial, such consulting services may be retained.

i. Alternative means of achieving the mitigation goal that will be considered include:

If the impact is attributable to groundwater pumping, cessation of groundwater pumping from wells that affect the impacted area would be the first consideration for mitigation. Also considered will be a change in the future management of groundwater pumping from the well to avoid F repetition of the impact.

Surface water application to repair, rehabilitate, and/or restore the impacts will be considered as an alternative. Any water supply needed for the proposed mitigation shall be evaluated as to its potential for inducing further adverse environmental impacts.

Revegetation of the affected environment shall be considered as an alternative. Generally, the preferred goal of revegetation would be to restore vegetation cover to the ecological viability which existed prior to the impact. A primary consideration in revegetation would be to use native species which grow in Owens Valley. Revegetation efforts will incorporate procedures to control weeds and fugitive dust. Full restoration may require a long period of time.

c. As part of each mitigation plan, the Technical Group shall develop a reporting and monitoring program. At least once per year, the Technical Group shall report, in writing to the Standing Committee, on the effectiveness of the mitigation plan in achieving its goal.

Should a mitigation plan fail to substantially achieve its goals, the Technical Group shall implement alternative, feasible mitigation, if any exists, that will achieve the goals. If no such alternative exists, a new mitigation goal will be developed and implemented for the afflicted area. The Technical Group shall report the change in writing to the Standing Committee, together with reasons for the change, and a new mitigation monitoring and reporting program will be adopted by the Technical Group.

d. If, through seasonal water balance calculations or through other means, the Technical Group projects that significant decreases or changes in vegetation could occur, the Technical Group will take such action as it deems feasible and necessary to avoid the projected impact. Such action would be in addition to the provisions for automatic well turn-off.

D. Other Vegetation

For management purposes, vegetation in Owens Valley has been divided into five management classifications based on the dominant vegetation species. However, each vegetation classification is comprised of vegetation species other than the dominant species.

1. <u>Management</u>

Certain vegetation of significant environmental value are not shown on the management maps because they are not the dominant species. This vegetation will be identified by the Technical Group for monitoring purposes on overlays to the management maps. Areas of this vegetation include riparian vegetation dependent upon springs and flowing wells, stands of tree willows and cottonwoods, and areas with rare or endangered species. The monitoring sites will be located in areas where there is a potential for impact to such vegetation by groundwater pumping or changes in surface water management practices (although certain areas of rare or endangered species will be monitored, these areas will not be publicly identified on the management maps in the interest of protecting such vegetation).

If, through field observation, monitoring, and other evaluations, it is determined that groundwater pumping or changes in surface water management practices has resulted in severe water deficit stress that could cause a significant decrease or change in this vegetation, the Technical Group will take such action as is feasible and necessary to prevent significant impacts and to reduce any impacts to a level that is not significant.

2. Monitoring

Monitoring at each identified site will consist of one or more field visits during the period when groundwater pumping and changes in surface water management practices could affect such vegetation in an attempt to obtain advance knowledge of potential water stress. Shallow piezometers will be installed and monitored where and when deemed necessary (for rare and endangered species, only a qualitative assessment will be made in order to minimize the disturbance from monitoring). If an impact is suspected, more intensive measurements, such as vegetation transect procedures, would be undertaken as determined appropriate by the Technical Group.

3. Mitigation

The procedures set forth in Section I.C will be used to determine whether an impact to vegetation of concern is measurable, attributable to groundwater pumping or changes in surface water management, and is significant, and thus, if a mitigation plan should be developed and implemented.

II. VEGETATION INVENTORY AND DEVELOPMENT OF VEGETATION MANAGEMENT MAPS

Section II of the Agreement provides that management maps that classify dominant vegetation on the Valley floor into five types are to be used in achieving the goals of the Agreement. Vegetation inventories that were conducted by the Department between 1984 and 1987 were used in compiling these maps. This section describes the vegetation mapping methods and the development of the management maps. The Technical Group is conducting a cooperative study of the vegetation map data base (see Section V). As a result of this study, the vegetation management maps and portions of this section will be revised in the future. A mapping technique that employed air photo analysis, field checking, and sampling transects was used to document the dominant vegetation cover.

Generally, vegetation inventories are used to document conditions over large land areas, providing a baseline for comparison to future vegetation cover. By regularly performing such a comparison, Inyo County and Los Angeles will monitor the effectiveness of the proposed hydrologic management techniques and make appropriate adjustments to meet the goals of the Agreement.

A. Inventory of Dominant Vegetation

The dominant vegetation of a total of 227,160 acres of Los Angeles-owned land in the Owens Valley was inventoried and mapped by LADWP between 1984 and 1987. All of the mapped acreage is within the Inyo County/Department of Water and Power Cooperative Vegetation Study area. The study area included portions of Chalfant Valley, Fish Slough, and the entire area from Bishop to Owens Lake. The mapping scale was 1:24,000.

1. Timing of Mapping Activities

The vegetation maps were produced through a combination of laboratory and field work that was divided for the north and south portions of the Valley. Table II.A.1 shows-by quad-the time frame of field work.

TABLE II.A.1

VEGETATION MAPPING - OWENS VALLEY

QUADRANGLE	MONTH & YEAR
Independence	September 1984 - September 1985
Bee Springs	September 1984 - September 1985
Manzanar	October 1985 - November 1985
Union Wash	November 1985 - December 1985
Lone Pine	January 1986 - March 1986
Blackrock	March 1986 - June 1986
Aberdeen	June 1986
New York Butte	July 1986
Tinemaha	July 1986 - August 1986
Fish Springs	September 1986
Big Pine	September 1986 - January 1987
Ulymeyer Spring	January 1987
Laws	February 1987 - April 1987
Poleta Canyon	May 1987 - July 1987
Fish Slough	July 1987 - September 1987
Bishop	September 1987

a. Mapping for the area from Independence to Owens Lake was accomplished during the period from September 1984 to March 1986.

b. The Blackrock area north to Fish Slough and Chalfant Valley was mapped between March 1986 and November 1987.

2. Methods for Vegetation Mapping

LADWP lands were defined into parcels based on historic and current land use and on contiguous assemblages of plants with relatively similar cover and composition. Historic land-use maps were consulted, air photographs were analyzed, and field sampling was performed. Vegetation parcels were ultimately classified into recognized plant communities based on a classification system used by the California Natural Diversity Data Base (Holland, 1986).

a. Historical references were consulted, including water and land-use maps, and 1944, 1968, 1973, and 1981 aerial photos of Owens Valley.

b. Color prints of aerial photographs, at a scale of 1:12,000, from July 1981 were used for the initial delineation of vegetation-parcels and for the actual field sampling. Black-and-white air photo prints from 1944, at a scale of 1:24,000, and 1968, at a scale of 1:12,000, were also used to verify abandoned agriculture.

c. The color and scale of the 1981 aerials permitted preliminary delineation of parcels on acetate overlays. The minimum mappable area for recognizing a parcel was selected at 20 acres. Areas of similar color and appearance were assumed to have somewhat uniform plant cover and species composition. The contrasts between types ranged from strong to very subtle.

d. Field sampling required visiting each parcel. Adjustments of the parcel boundaries were made in the field, if necessary. Field sampling of the vegetation in each parcel was accomplished by vegetation transect. The line-point transect was chosen as the technique because it is a simple and rapid method to characterize vegetation cover (Kuchler, 1967).

   ii. The line-point method was adopted from techniques presented by Heady, Gibbens, and Powell (1959). A 100-foot metal engineer's chain (or tape), with 1-foot markers, was stretched over the vegetation selected for sampling.

   iii. At each 1-foot marker, the tallest plant cover as seen from a vertical projection was recorded; plants existing as an understory and nonleafy categories, such as ground cover and mulch, were not recorded.

   iv. A minimum of five transects were run on each parcel. If the vegetation cover was particularly heterogeneous, a qualitative method was employed in selecting additional transects. The transect data were checked visually and additional transects were then run depending upon the degree of variability. If the transect data were highly variable, up to seven additional transects were run. Aerial photos were an aid in locating the transects.

   v. Transects were located visually by choosing lines that appeared to cover the representative units of vegetation within the parcel. With regard to the parcel area, transect locations were generally toward the center of the parcels in order to avoid transitional areas at the parcel edges.

e. The transect data collected in the field was evaluated to determine the percent cover of each species calculated by the total of the first contacts for the species divided by the total sampling points used. From these data, a final vegetation description was compiled for each parcel (Transect Sheet, Appendix A). The description includes the percent of live vegetation cover and the percent composition of each plant species. Vegetation cover is defined as the crown cover of all live plants in relation to the ground surface. Species composition is synonymous with "relative cover" and expresses the percent contribution by a species to the land surface area covered by living plants.

f. The parcel boundary lines were transferred to orthophoto quadrangles at 1:24,000 scale. The final maps overlay the USGS 7.5-minute quads. Each parcel was numbered and has a corresponding vegetation description. The acreage of each parcel was determined by planimetry, and the vegetation cover for the parcel was entered into a computer data base.

g. The final stage in mapping was the selection of a classification system. The system used is based on Cheatham and Haller's classification of California" habitat types (Cheatham and Haller, 1975), as revised to plant community descriptions (Holland, 1986). This system was further refined for the Owens Valley using the data collected for this inventory. To suit the needs of the Cooperative Vegetation Study, six additional plant communities and a non-native vegetation and miscellaneous lands category were added.

   The classification system used is primarily floristic; hence, parcels with similar species composition were grouped together. In instances where a parcel could fit into two different communities, factors such as soil type, water table depth, and landscape

B. Projecting Evapotranspiration from Dominant Vegetation

The transpiration from each of the mapped parcels was calculated based on data gathered during the Cooperative Vegetation Study and on data presented in the literature. Evaporation was estimated either (1) as one-half the average precipitation for the quadrangle in which the parcel was located, br (2) as an amount of water equal to one-half the average precipitation estimated as in (1) added to a fixed, one-dimensional rate (Table II.B.4) which is multiplied by the area of bare ground. The quadrangle-average precipitation was computed from maps of isohyetal contours (LADWP, 1976).

1. The transpiration values for the six most dominant Owens Valley plant species were obtained from the Cooperative Vegetation Study, Phase I (Groeneveld et al, 1986). The report yielded equations for transpiration and leaf area index for each species as a function of the day of the year based on field data. The equations were calculated to represent the annual amount of water transpired on a site with 100% cover by the species. Therefore, to obtain parcel transpiration by species, the values were expressed as a rate per 100% cover that could be decremented by the actual fractional cover measured within the parcel. The transpiration equations for six dominant perennial species are presented in Table II.B.I.

2. Annual values for transpiration based on percent cover for eight other species were determined from the literature (Table II.B.1).

3. For the species for which transpiration was neither documented by the Cooperative Studies nor was available in the literature, transpiration was set equivalent to the weighted mean for the documented species that occurred within the parcel. If transpiration rates of no species were known within a parcel, the annual transpiration rate for all other parcels within the quadrangle was assigned.

TABLE II.B.1

TRANSPIRATION VALUES

SPECIES SYMBOL	COMMON NAME	TRANS. (in.)	SOURCE
ATCO	Shadscale	8.00	Groeneveld*
ATTO	Nevada Saltbush	17.30	Groeneveld
CHNA2	Rubber Rabbitbrush	36.93	Groeneveld
DISPS2	Saltgrass (sandy soil)	10.40	Groeneveld
DISPS2	Saltgrass (silty soil)	20.33	Groeneveld
SAVE4	Greasewood	35-89	Groeneveld
SPAI	Alkali Sacaton (sandy soil)	11.11	Groeneveld
SPAI	Alkali Sacaton (silty soil)	19.41	Groeneveld
ARTRT	Basin Big Sagebrush	4.06	Branson, et al Miller, et al
CELA	Winterfat	2.99	Branson, et al Moore, et al
GRSP	Spiny Hopsage	5.20	Branson, et al
TEAX	Longspine Horsebrush	3.31	Branson, et al
SAGOV	Goodding Willow	48.00	Robinson
SALIX	Willow	48.00	Robinson
TARA	Saltcedar	66.00	Gay
IRAG	Irrigated Agriculture	35.04	DWP Records
URBAN	Owens Valley Towns	24.00	DWP Records

• Cooperative Vegetation Study - Phase 1

4. Evaporative water loss from precipitation was estimated to be 50 percent of the average annual precipitation in the quadrangle applied over the entire acreage (Groeneveld, 1989). Additional evaporation values have been added for those areas influenced by surface water (Table II.B.4.). These one-dimensional bare soil evaporation rates were estimated and were used to calculate an average bare-soil evaporation rate.

TABLE II.B.4

EVAPORATION VALUES

CLASSIFICATION	COMMON NAME	EVAP (in.)	SOURCE
Various	Parcels Irrigated with Stockwater or operational (surplus) Water Releases	7.20	Estimated*
60000	Riparian	24.00	Estimated*
40000	Native Grass Meadows	7.20	Estimated*
13100	Permanent Bodies of Water	60.00	DWP Reservoir Records*
13200	Intermittent Bodies of Water	36.00	Estimated from DWP Reservoir Records*

* Technical Group, September 25, 1986; Inyo County/LADWP/USGS Cooperative Owens Valley Groundwater/Vegetation Studies, January 22, 1987

NOTE: These evaporation values are applied to the bare ground in the parcel (or to the water surface in the case of lakes and ponds) in addition to one-half the average annual precipitation in the quadrangle applied as evaporation over the entire acreage.

5. For each parcel, as represented on the sample printout in the Appendix A, the following information can be found: annual transpiration in feet, annual transpiration in acre-feet, annual evaporation in feet, annual evaporation in acre-feet, annual evapotranspiration (ET) in acre-feet, annual ET in feet, and annual ET in inches.

C. Vegetation Management Maps and Goals

The previous discussion focused on the development of vegetation community maps and the calculation of average annual evapotranspiration from each parcel.

The plant community classification and plant water use calculations for parcels were combined to produce a series of management maps.

The management maps, which are attached to the Agreement, classify 227,160 acres of vegetation into five management types-A through E. The five color-coded categories were derived based on the vegetation community maps previously described and on water use. The categories, in increasing alphabetical order, generally show increasing water use.

The maps depict each color-coded category as either inside or outside an area of potential impact that is based on a worse-case pumping and drought condition. The derivation of the potential impact area is more fully discussed in Section IV. Other features on the maps include roads and towns, vegetation monitoring sites, and LADWP pumping wells.

Vegetation was assigned to Types A through E by first calculating the average ET of each community. The results are presented in Table II.C.

TABLE II.C

	AVERAGE ET

CODE#	COMMUNITY	(INCHES)-
14000	Barren Lands	3.12
34100	Mojave Creosote Bush Scrub	3.60
34210	Mojave Mixed Woody Scrub	3.48
34300	Blackbrush Scrub	4.08
35100	Great Basin Mixed Scrub	4.20
35210	Big Sagebrush Scrub	4.44
36110	Desert Saltbush Scrub	4.08
36120	Desert.Sink Scrub	5.76
36130	Desert Greasewood Scrub	4.68
36140	Shadscale Scrub	3.60
46000	Alkali Playa	2.04
35400	Rabbitbrush Scrub	7.08
36150	Nevada Saltbush Scrub	7.68
45310	Alkali Meadow	11.04
45320	Alkali Seep	13.80
45340	Rabbitbrush Meadow	10.68
45350	Nevada Saltbush Meadow	9.60
52320	Transmontane Alkali Marsh	26.04
61610	Great Basin Riparian Forest	40.44
61700	Mojave Riparian Forest	33.12
63600	Great Basin Riparian Scrub	36.84
63810	Tamarisk Scrub	17.28
11000	Irrigate Agriculture	38.04
13100	Permanent Lakes/Reservoirs	62.88
13200	Intermittent Ponds	39.12
45330	Rush/Sedge Meadow	17.04
45500	Non-native Meadow	27.48
76100	Black Locust Woodland	25.68

1. All vegetation communities which had estimated annual evapotranspiration approximately equal to or less than the average annual precipitation (5.72 inches for all quads) were classified as Type A management areas and are shown as-white on the management maps. Type A consists of all parcels in communities with average ET less than or equal to 5.76 inches.

   The remaining vegetation communities for the entire mapped area were sorted using the computer data base to determine other parcels, regardless of the vegetation community, which had an estimated annual evapotranspiration rate less than the quadrangle-average precipitation. These parcels were also included in Type A classification.

2. Scrub communities with an estimated average annual evapotranspiration greater than estimated average precipitation within the quadrangle were classified as Type B. Type B vegetation primarily includes the Rabbitbrush Scrub and Nevada Saltbush Scrub communities and is shown as yellow on the management maps.

3. All grass-dominated vegetation parcels with an estimated annual evapotranspiration greater than quadrangle-average precipitation were classified as Type C and represented in green on the management maps.

4. All parcels dominated by riparian and marshland vegetation with an estimated annual average evapotranspiration greater than precipitation were classified as Type D and represented as red on the management maps.

5. All lands provided with surface water for irrigation, including enhancement/mitigation projects, recreation areas, wildlife habitats, stock water supplies, and water spreading areas, are classified as Type E and are shown as blue on the management maps.

III. VEGETATION MONITORING

Monitoring is the means to determine whether management of groundwater and surface water will achieve the goals of the Agreement. The intensity of the monitoring effort within the Owens Valley is structured for vegetation type and location, whether outside, on the periphery, or within a well field. Monitoring intensity will be greatest within well fields and will lessen with distance away from the pumping wells.

Within well fields, vegetation will be monitored using sites established to permit projection of plant water balance according to Sections III.D through III.C.

The correlation of individual wells and existing monitoring sites is summarized in Table I.C.2.

Future monitoring sites may be added based on the criteria set forth in Section I.C.

A. Locating and Overlaying Monitoring Data

The monitoring program will require a data base which can tie geographic information to historic and current hydrologic conditions and vegetation data. As new concepts are developed and agreed upon, such as remote sensing and geographic information systems (see Section V. "Further Studies"), they will be integrated into the monitoring system.

1. Incorporation of Existing Data

   Existing data will form the data base to interpret vegetation vigor and community changes.

   a. Maps of Vegetation and Soils

      Both the soil inventory of Owens Valley, conducted by the Soil Conservation Service in the mid 1980s, and vegetation data from the 1984-87 Cooperative Studies Vegetation inventory will be utilized.

   b. Areas of impacts from changed water management practices and-resultant-mitigation, if any.

   c. All hydrologic features, such as lakes, canals, and streams (updated as necessary).

   d. Location and data from pumping wells, test wells, and monitoring sites.

   e. Interpretive features from the hydrologic and vegetation maps. A mixture of permanent and updatable information would be placed on one or more overlays, including:

      i. Vegetation management classes (A through E as written in the Agreement).

      ii. Areas of rare or endangered species (although certain areas of rare and endangered species will be monitored, these areas will not be publicly identified on the management maps in the interest of protecting such vegetation).

   f. Land ownership maps.

   g. USGS quadrangle maps.

   h. Cultural features, such as roads, towns, campgrounds, and bicycle or equestrian paths.

   i. Land use maps showing irrigation.

   j. Burned areas resulting from accidental fires or through range management.

B. Remote Sensing

Remote sensing is a valuable tool for land management. At present, the remote sensing program is presented as a study in Section V. The remote sensing program will be presented here once it has been tailored to the Owens Valley.

C. Monitoring Leaf Area and Plant Recruitment

At sites where water balance projections are made, leaf area index (LAI) will be used to compare vegetation growth among sites and growing years and to project seasonal plant water use. LAI will be evaluated by the point frame during expected peak leaf growth. Under nondrought conditions and without excessive summer rains, the growing season peak has been found to occur at approximately the mid-point of the calendar year (Groeneveld et al, 1986).

Quantitative yearly recruitment inventories at all monitoring sites will include woody and herbaceous perennial species, and weedy and nonweedy annual species. The intent of the recruitment studies is to determine community processes in relation to hydrologic management and ambient conditions, and to determine long-term trends of vegetation dynamics (see Section V).

1. <u>Leaf Area Evaluated by Permanent Transect</u>

   a. Transects are to be 100 m long, marked by permanent stakes. The beginning of each transect, which is the zero point for point-frame records, will be marked. Facing along the transect from the zero point, right- and left-hand sides will be noted. The transect will receive point-frame measurement from the right-hand side only.

   b. Sub-transects of 30 m length will be located on each 100-m transect; these will also be marked by permanent stakes.

   c. Workers will avoid walking across the transect line in order to preserve the vegetation cover.

2. <u>Leaf Area to be Determined by Point Frame</u>

   Point-frame data will be collected to estimate ET for the monitoring sites and to measure vegetation composition and LAI.

   a. Point-frame pin intervals will be 30 cm. Pin length will be sufficiently long to permit measurement on plants of the stature encountered at each transect.

   b. A measuring tape will be stretched between the permanent stakes at each end of the transect. The stretched tape aligns the point frame, and guides pin interval location.

   c. Pins will be sharpened to a point on the end used for measurement.

   d. All contacts with plant parts by the sharpened pin points lowered from the frame will be recorded.

      i. The first contact of the pin with the transpirative surface (leaf tissue and/or stem tissue, depending upon species) will be recorded by species.

      ii. ii.. Subsequent contacts of the pin with transpirative surfaces will be recorded by species.

      iii. Contact of the pin point with dead plant material lying on the ground will be recorded as “mulch.”

      iv. Contact with standing but nontranspiring plant material will be recorded as “standing mulch.” Only one “standing mulch” per pin is recorded.

v. Contacts consist of either transpirative foliage, mulch, standing mulch, or bare ground.

e. Total number of hits on the more abundant Owens Valley species can be used to calculate leaf area index. There are six species which dominate the Valley floor. Transpiration data has been collected for each of the six species to enable projection of soil-to-plant water balance at monitoring sites (Groeneveld et al, 1986). Table II.C.2.e presents the species with recognized standardized abbreviations (USDA SCS, 1971).

TABLE III.C.2.e
ABUNDANT SPECIES OF THE OWENS VALLEY FLOOR

SPECIES	RECOGNIZED ABBREVIATION
Atriplex torrevi	ATTO
Chrysothamnus nauseosus	CHNA
Sarcobatus vermiculatus	SAVE
Sporobolus airoides	SPAI
Distichlis spicata	DISP
Atriplex confertifolia	ATCO

3. Applying Leaf Area Data by Normal Curve

The leaf area measurements are used for calculating plant water requirements. At present, this technique which uses plant cover is under review to determine whether leaf area index permits more accurate estimation of transpiration (see Section V, dealing with further studies).

A normal curve will be used to describe leaf area through a growing season using time as the independent variable. The ends of this curve have been fitted in order to approach zero leaf area on March 25 and October 15 (DOY 84 and 289, respectively).

a. The peak of the growing season will be established as July 4 (DOY 186). The magnitude of this curve at its peak will be determined by the late June point-frame measurements obtained at each of the monitoring sites.

b. Leaf area during any day of the summer will then be simulated according to a fitted normal curve:

$$\text{LAI}\ i = \sum_{i=1}^{\Pi} \text{LAI}_{\max\ j}\ e^{\frac{-(t-186)^2}{3000}}$$

where: t = day of year (DOY)
i = ith species
j = jth site
LAI_{max} = peak season LAI

4. Leaf Area Monitoring will Occur Three Times Each Year

a. Each 100 m permanent transect will be monitored within one week before and two weeks after summer solstice. The 30 m sub-transect data for this time period will be extracted from the 100 m data.

b. Within one week before and two weeks after April 21, and again for August 21, point-frame measurements will be taken at the 30 m sub-transect.

5. <u>Plant Recruitment Studies (see also Section V)</u>

Permanent belt transects will be used to evaluate the recruitment of herbaceous and woody perennial species.

a. Ten belt transects, 1 m wide and each 10 m long, will be located on the left-hand side of the transect as viewed facing along the transect from the zero end.

b. Evaluation of belt transects will be performed during three periods:

   i. Herbaceous species will be evaluated within one week of the April point-frame measurements.

   ii. Herbaceous species will again be evaluated within one week of the peak season (late June) point-frame measurements.

   iii. Both herbaceous and woody perennial species will be evaluated within one week of the August point-frame measurements.

c. Data collection for nonwoody species within the belt transects will be standardized to enable easy data analysis.

   i. All species will be identified by their standardized abbreviations.

   ii. All individuals of herbaceous perennials and annual species will be recorded.

d. Data collection for woody perennials that are recognizably younger than surrounding vegetation will be recorded into three age classes:

   i. Plants germinated during the current year

   ii. Plants germinated the previous year

   iii. Plants germinated two or more years previously but still having recognizable juvenile characteristics, such as:

   - Comparatively small stature
   - Relatively thin stem-base cross section
   - Lack of flowering/seed set

D. Projecting Transpiration through the Growing Season

Transpiration requirements of projecting soil-to-plant water balance for the permanent monitoring sites will be based on the leaf-area measured for each species at the peak of the growing season. Peak season LAI has been chosen for estimation of transpiration since this is the time when the rate of change in leaf area is minimal. Normal curves of leaf area will be calculated using actual monitoring data as described under Section III.C.3.

The method for calculation of transpiration is under investigation in Section V with the study of methods for estimating leaf area. The most accurate and efficient method for estimating transpiration at monitoring sites will be determined through this study and changes to the following technique may occur.

The calculation of transpiration for each species at a monitoring site through the growing season will necessitate summation of each day's projected leaf area multiplied by each day's unit leaf-area transpiration. Transpiration will be apportioned using quadratic curves established or adopted for each species from data obtained under nondrought conditions. It is realized that the Valley-floor plant species have the capability to reduce transpiration during periods of soil water deficit and, therefore, actual unit leaf-area transpiration rates will often be less than those projected using data from nondrought conditions. Use of transpiration data gathered under relatively normal soil water conditions provide a safeguard against possible underestimation errors during field measurement.

The transpiration requirement determined using the linked curves will be compared to the available soil water to project whether sufficient water remains to supply the vegetation for the upcoming growing season.

1. Polynomial curves have been developed to describe unit-leaf-area transpiration using data established for each of the abundant species that grow on the Owens Valley floor.

   a. Transpiration is represented by second order polynomial equations which describe downward-opening parabolas. Day of year (DOY) was used as the independent variable. "X" intercepts for this curve were chosen to be the approximate dates of leaf out and leaf drop: March 25 and October 15 (DOY 84 and 289, respectively).

$$Q_j = \sum_{i=1}^{n} b_{0i} + b_{li}t + b_{2i}t^2$$

where: t = day of year
j = j^{th} site
i = i^{th} species
& = regression derived constants

   b. The polynomial curves for each species have been calculated using data excerpted from the Cooperative Studies data base. The data chosen represent relatively normal conditions for the plants with the water table in its historic positions. Seasonal curves of transpiration for each species and each site are used to predict peak mid-season transpiration values (on DOY 186). These peak values are then averaged for each species. Polynomial regression is then performed using the mean peak-season transpiration and the zero points for the start and finish of the growing season on March 25 and October 15 (DOY 84 and 289, respectively).

   c. The Cooperative Studies data base has permitted the establishment of curves for the six abundant Valley-floor species. The predictors for these curves will be used to calculate transpiration on a unit-leaf-area basis. The curves represented in Table III.D.l.c predict transpiration as either volume (1 m^{-2} d^{-1}) or as a one-dimensional value (mm d^1).

TABLE III.D.I.c

POLYNOMIAL PREDICTORS FOR TRANSPIRATION OF DOCUMENTED SPECIES*

SAVE4:	Q	=	-4.78 + 0.0823t - 0.000205 t^2
CHNA2:	Q	=	-4.140 + 0.0898t - O.OOO25Ot^2
ATCO:	Q	=	-0.611 + 0.0190t _ 0.00051t^2
ATTO:	Q	=	-2.290 + 0.0462t - 0.000125t^2
DISP2: (sandy soil)	Q	=	-2.470 + 0.0496t - 0.000132 t^2
DISP2: (silty soil)	Q	=	-5.330 + 0.1060t - 0.000291 t^2

SPAI: (sandy soil)	Q	=	$-2.840 + 0.0516t - 0.000137t^2$
SPAI: (silty soil)	Q	=	$-5.50 + 0.1010t - 0.000279t^2$

- t = DOY

d. The remainder of the Valley-floor species did not receive individual transpiration measurements. For the species for which transpiration was neither documented by the above studies nor was available in the literature, transpiration was set to the weighted mean for the documented species that occurred within the transect at each monitoring site.

2. Calculation of Transpiration at Each Monitoring Site

For each plant species at each site, transpiration through any time period during the growing season will be calculated for each day by multiplying the leaf area (determined using a normal curve described in Section III.C.3) by the transpiration presented in Section III.D.1.

The per-species water use will be calculated for the desired time period by summing the daily product of leaf area and transpiration through the days of the desired period.

The total transpiration for the vegetation at each monitoring site will be calculated as the sum of transpiration for each species or species grouping evaluated through the desired time period.

If an estimation of transpiration for a monitoring site is desired for the entire growing season, the computation will be evaluated through the period between leaf out (DOY is 84) and leaf drop (DOY is 289).

Transpiration for a monitoring site through a portion of the growing season will be calculated in the same manner, but the calculation will be between the selected starting and ending days. For example, if the second half of the growing season is chosen, the calculation will be performed between days corresponding to mid-season (DOY is 186) and leaf drop (DOY is 289).

The formula for this computation is:

$$Q_j = \sum_{I=1}^{n} \int_{t\,start}^{t\,end} \left[\left(\mathrm{LAI}_{max}\, e^{\frac{-(t-186)^2}{3000}} \right) \left(\hat{a}_{0i} + \hat{a}_{1i}t + \hat{a}_{2i}t^2 \right) \right] dt$$

where: t = day of year (DOY)
j = jth site
i = ith species
B = regression derived constants
LAImax = leaf area index measured during the growing season peak

E. Annual Biomass Measurements

1. Introduction

Annual herbage productivity measurements are currently being collected on Owens Valley plant communities in conjunction with the Benton-Owens Valley Soil Survey. Long-term monitoring sites have been selected on several of the plant communities and soil types. Data is collected in April, May, and June during peak growth.

Productivity accurately reflects the vigor or health of a plant or community. Changes or modifications of any growth factor, such as soil fertility, soil moisture, rainfall, or the biotic influences of insects, rodents, or livestock grazing, affect the vigor and, therefore, the productivity of a plant (Cook and Stubbendieck, 1986).

2. Method

A double-sampling method (Wilm, et al, 1944; Hilmon, 1959) is used in deriving production and composition determinations. A study area is selected for each soil taxonomic unit, and is based on uniformity of vegetation within that unit. Ten random plots are selected. Plot size varies depending upon the vegetation density. The following plot sizes and shapes are used for sampling:

.96 ft^2	circular -	meadow communities
9.6 ft^2	rectangular -	shrub and shrub/grass communities
96. ft^2	rectangular -	sparse shrub communities

Nested plots (9.6 ft^2/96 ft^2) are also used in sparse shrub stands in years with heavy annual forb production.

A weight unit is established for each species in the study area, and the new growth is clipped and weighed. A weight unit may be a branch of a shrub, half of a grass plant, or ten forbs of average size. Weights are then estimated, based on the weight unit, for the species in each of the ten plots. Two plots are then selected for harvesting. They must include all or most of the species in the estimated plots. Green weights are taken for all the species in both plots. The clipped growth is air-dried for three weeks and reweighed. Regression analysis is applied to the data with estimated weights as the dependent variable and clipped weights as the independent variable. All estimated values are then adjusted by the regression equation. Production, in pounds per acre, can then be calculated:

$$\frac{\text{Weight of all plots}}{\text{\# of all plots}} \times \text{\% dry weight} \times \text{plot correction factor} \times \text{plot size conversion factor}$$

3. Application of Production Data

Ten production sites have been selected as long-term well field monitoring sites (Table III.E.3). Nine sites are located outside vegetation management zones, as determined by the Cooperative Agreement. The Division soil site is located east of Blackrock Springs, within a predicted drawdown area although no drawdown has occurred, and the site is being redesignated as a control site.

The data will be used to provide a qualitative evaluation of the influence of precipitation on vegetation productivity. It will be compared with leaf area and vegetative cover data collected at control sites to evaluate the change in vegetation over time. The data collected at the control sites and at the productivity sites will be compared to monitoring sites with similar soils and vegetation. This comparison will be utilized to qualitatively evaluate the effects of fluctuations in precipitation and the resulting changes in vegetation vigor.

TABLE III.E.3
LONG-TERM PRODUCTION MONITORING SITES

Annual productivity measurements are being collected on Owens Valley plant communities in conjunction with the Benton-Owens Valley Soil Survey. Data is collected during the months of April, May and June when vegetation has reached peak growth. Current year production (1989) compared to previous years' production are shown below.

							PRODUCTION #/AC, (% LIVE COVER)			
WELL FIELD AREA	SOIL NAME &TEXTURE*	TRANSECT REFERENCE	PHOTO NO.	QUAD	VEGETATION PARCEL NO.	CLASSIFICATION CODE	1985	1986	1987	1988
Bairs-George	Lubkin	85-114	12-6	Manzanar	1	34210		596	57	77
Control	GR-LS							(19)	(13)	(16)
Symmes-Shepherd	Manzanar	84-22	10-19	Independence	148	45310	3005	2139	843	1103
Control	SL (						(47)	(34)	(24)	(25)
Symmes-Shepherd	Mazourka	84-25	8-27	Bee Springs	2	36130			385	804
Control	S						(10)	(16)	(7)	(9)
Taboose-Aberdeen	Division	85-112	13-17	Blackrock	69	36120		723	179	222
Control	VFSL							(110)	(9)	(8)
Independence-Oak	Shondow	85-70	12-19	Independence	79	45310	1204	1141	704	693
Control	L						(36)	(40)	(29)	(25)
Independence-Oak	Winnedumah	83-30	11-18	Independence	95	36150		1287	571	799
Control	SIL							(25)	(27)	(27)
Big Pine-Crater Mtn.	Hessica	87-ET-110	14-36	Uhlmeyer	54	36120			252	194
Control	SL								(11)	(10)
Bishop-Warm Springs	Westguard	87-ET-143	20-11	Big Pine	21	36120				105
Control	S									(7)
Bishop-Warm Springs	Lucerne	87-ET-197	25-4	Bishop	172	35100			280	36
Control	GR-LS								(25)	(9)
Bishop-Warm Springs	Poleta	88-ET-9	23-21	Laws	185	36140			173	40
Control	S								(11)	(10)

*Soil Texture:

GR-LS = gravelly loamy sand
S = sand
SIL = slit loam
VFSL = very fine sandy loam
L = loam

F. Soil Water Measurements

Permanent monitoring sites have been established. These sites are located (1) within well fields where water tables are known or expected to fluctuate due to groundwater pumping, and (2) in control areas outside of the influence of well field pumping to provide for comparison to plant responses within the well fields.

When groundwater pumping lowers a shallow water table below the effective root zone of the plants, retained soil water provides a supply for the vegetation f or an uncertain period. The period that the retained soil water can maintain the vegetation is determined by type and cover of the vegetation, the water-holding capacity of soil, and starting water content. The objective for the measurements described in this section is to project a soil-to-plant water balance. This calculation determines whether the plant water requirement (project transpiration) will be met by the plant-available soil water.

Psychrometers are used for measuring soil water potential. Soil water potential is used to estimate the plant-available soil water. The limitation for plant withdrawal of soil water is governed by the logarithmic relationship of water potential to soil water content. Because of this relationship, assessment of the soil water available to plants would tend to have measurement errors compounded logarithmically if the measurements and interpretations relied solely upon soil water content. The monitoring techniques that have been chosen use direct measurements of soil water potential which are then converted to soil water content using the Miller method. This technique relates the soil water potential with soil water content using a technique suggested by Reuben F. Miller'(Miller, 1983) and described and tested in Sorenson and others (1989).

Water potential measurements are being taken at one representative location within the soil of each monitoring site. Soil water measurements are obtained as close to the vegetation measured by the permanent transects as possible. Calculations of plant-available soil water that are made from these measurements are then related to the water needs projected for the surrounding vegetation cover using the data established by vegetation transect.

The soil column at each of the monitoring sites is broken into four, 1 m-deep slices. The available water is calculated for each depth slice. The total water available to the plants is then estimated based on a summation of the plant-available water content for each slice located in the rooting zone.

1. <u>Measuring Techniques for Evaluation of Soil Water</u>

Three types of measurements are used for in situ evaluation of soil water at monitoring sites. These measurements are obtained using soil psychrometers, piezometers, and neutron probes.

a. Soil psychrometers are used to provide the necessary data for calculation of soil water potential and, through use of the "Miller Method," calculation of the soil water content by weight. For ease of implantation and removal, psychrometers are mounted within cassettes (details of cassette construction are shown on Figure III.F.l.a).

  i. Soil psychrometers are mounted-into cassettes made of polyvinyl chloride (PVC) tubing. Three psychrometers are mounted at the tip of each cassette to provide for statistical evaluation of operation.

  ii. Cassettes are constructed so as to be water tight in the event of water table recovery. Cassette heads are checked for water tightness following their construction.

  iii. Psychrometers are installed at 0.5 m, 1.5 m, 2.5 m, and 3.5 m depths. These depths have been chosen to be representative of 1 m-thick soil slices extending to 4 m.

iv. Psychrometers will not be implanted into the water table.

v. Installation of psychrometers follows the procedure outlined in Box III.F.I.a.v. The psychrometer leads are accessed through insulated boxes buried 10 cm below the soil surface (see Figure III.F.l.a). Fiberglass insulation is packed over the tops of the psychrometers within the box to further reduce the effect of near-surface temperature gradients.

BOX III.F.l.a.v
INSTALLING PSYCHROMETERS FOR THE MONITORING PROGRAM

STEP 1: Assemble the following items:
Clay-water slurry of the consistency of honey
Soil cans with zip-closure bag liners (6-1/2" x 5-7/8")
2 Stainless steel mixing bowls of 6 quart capacity
Large zip-closure bags (10-1/2" x 11-3/4")
2-inch Soil auger with extensions, wrenches, and a rubber mallet
Measuring tape with metric markings
Madera sampler and soil cans for volumetric soil sampling
Indelible felt-tip marker
Cooler and electrical tape

STEP 2: Select implantation site. This should not be on a low spot and should be within 30 m of the permanent transect described in Section II.A.1.

STEP 3: Measure and mark the depth desired for the psychrometer on the shaft of the auger. Also, place marks at 5 cm below, and 15 cm and 45 cm above the desired implantation depth.

STEP 4: Core, and reserve to the side of the hole, all of the soil excavated down to a point 45 cm above the intended depth for the psychrometer.

STEP 5: Core and reserve the next 30 cm of soil. Seal within a large plastic zip-closure bag and place in bowl A.

STEP 6: Core the next 10 cm of soil and reserve, sealed within a large zip-closure bag within bowl B.

STEP 7: Carefully obtain a volumetric sample with the Madera sampler. Place this in a soil can.

STEP 8: Core to 5 cm below the intended point of psychrometer installation and also reserve with the sample in bowl B.

STEP 9: Thoroughly mix the contents of bowl B. Fill a soil can (to the extent permitted by the bag liners) with a subsample of bowl B. Seal the sample within a small zip-closure plastic bag, place the lid on the can, seal the can lid with electrical tape, and pack in an insulated cooler for the trip to the lab.

STEP 10: Partially back fill the hole with a small portion of the contents from bowl B, and lower the psychrometer cassette into place. Gently impress the psychrometers into place with minimal, gentle, back-and-forth twisting motions.

STEP 11: Back fill remaining contents of bowl B evenly around the cassette shaft. Gently rock the cassette shaft butt, pressing downward gently at the same time.

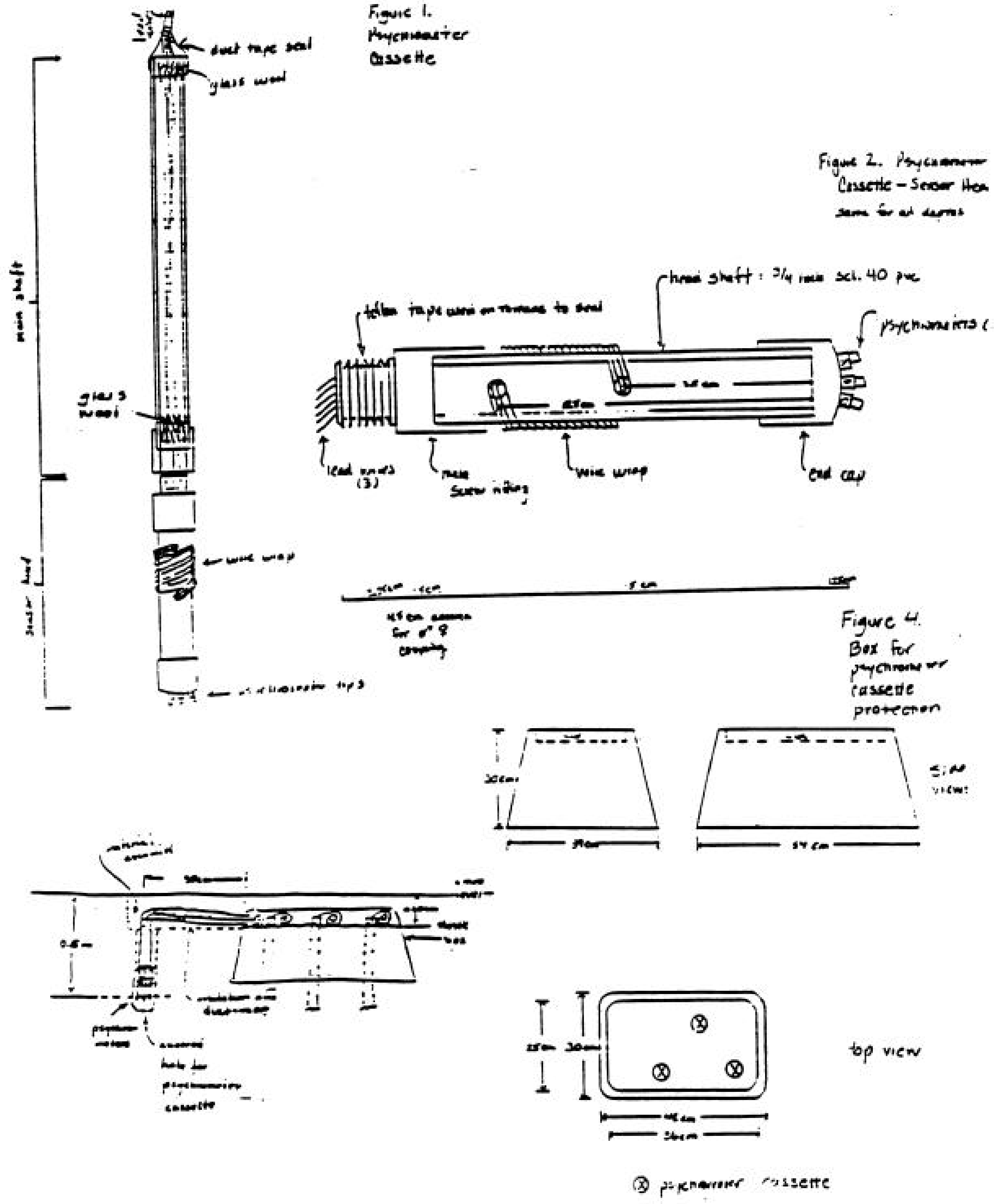
STEP 12: Back fill the hole with contents of bowl A. Again, gently rock the cassette while pressing downward.

STEP 13: Pour about 1 liter of clay slurry down the hole for sealing against vapor migration or downward water percolation.

STEP 14: Back fill the remainder of the hole with soil reserved adjacent to the hole.

STEP 15: Process the soil samples in the laboratory to obtain the water potential and water content of the sample obtained in Step 9, and the dry bulk density from Step 7.

FIGURE III.F.1.a



vi. Although factory calibration is performed for psychrometers, each psychrometer will be recalibrated prior to incorporation into a cassette. This is performed to double check correct operation and to confirm that the sensor tips are water -tight. Psychrometer calibration records will be kept to track each psychrometer through its useful life. Psychrometer calibration is described within Box III.F.I.a.vi.

BOX III.F.I.a.vi

PSYCHROMETER CALIBRATION

STEP 1: Mix a 0.5 molal solution of NaCl in distilled water according to specification in Bulletin 484*of the Utah Agricultural Experiment Station.
STEP 2: Seal psychrometers within glass bottles filled with the NaCl solution.
STEP 3: Place the sealed glass bottles within a water bath (necks of the bottles not submerged) within an insulated cooler.
STEP 4: Close the cooler with the wire leads protruding to access microvoltmeter measurements for the psychrometers.
STEP 5: Seal around the access holes for the wire leads.
STEP 6: Place the cooler containing water bath and the instrumented bottles within an environment which does not have more than 30 Celsius diurnal change of temperature for 12 to 24 hours to allow complete equilibration of the system.
STEP 7: Obtain microvolt readings of the psychrometers and record the zero-offset (measure of the temperature gradients in the system) and temperature.
STEP 8: Calculate the constant "gamma" in bars/microvolt to calibrate microvolt readings to interpret water potential. This calculation requires correcting the water potential of the solution for temperature using the following formula (Wescor, undated):
Corrected reading = Reading / (0.325 + 0.027T)
where T = ^{0}Celsius

vii. Psychrometer readings are taken according to the manufacturer's procedures. Psychrometer readings are corrected for temperature and then multiplied by the calibration factor (obtained as described above) for conversion into water potential.

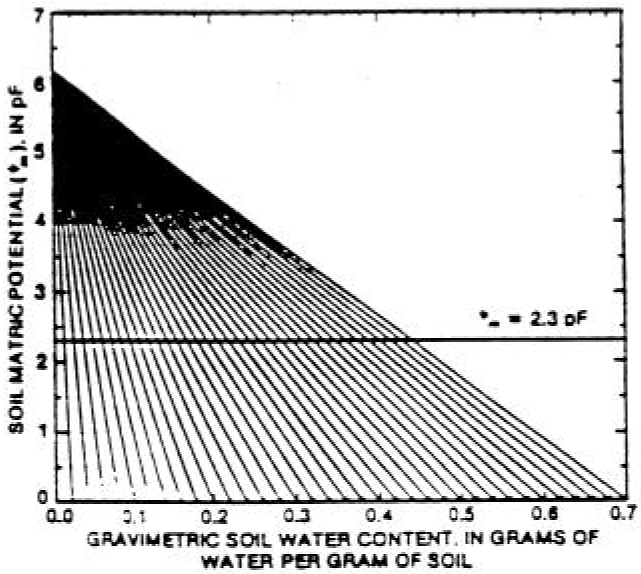
b. The neutron probe will be used in a qualitative manner to inspect the relative soil water content in the profile between the depths at which the psychrometers are installed.

c. Piezometers extending to a depth of at least 10 m will be installed at each monitoring site to access and measure the water table. The method of installation when closer than 50 m to the vegetation transect or soil water instruments will be by augering. If implanted by jetting, piezometers will not be placed closer than 50 m to any point for measurement of soil water or vegetation, and any surplus water from the jetting will not be permitted to flow toward the monitoring areas. The piezometers will be located as close as possible to the monitoring site, but outside possible influence from ditches, irrigation, or other factors which may affect water table levels.

2. Soil water content is calculated from the soil water potential measurements by a procedure which uses a family of characteristic curves. The technique is described in Box III.F.2.

BOX III.F.2

A FAMILY OF CHARACTERISTIC CURVES FOR MINERAL SOILS



The above graph presents a soil water characteristics model which relates soil pF to the weight-fraction soil water content as presented in Sorenson and others (1989). The application of these curves for interpretation of soil water content is the "Miller Method." Toward the left side of the graph, the slopes indicate a rapid change of soil water potential from only a slight decrease in soil water content. This corresponds to coarse-textured soils, such as gravelly sands. Clayey textured soils, found toward the right-hand side of the graph, yield much greater amounts of water for each unit decrease of pF. A quadratic formula (Sorenson and others, 1989) may be used to calculate intercept and slope values which describe the curve for each soil:

where: B = 5.56 (a constant derived by Sorenson and others, 1989)
XM = 0.888 (a constant derived by Sorenson and others, 1989)
2g = the gravimetric soil water content,in grams of water per gram of soil measured on a sample obtained from the field
Qm = the matric potential, in pF, measured on a sample obtained from the field

3. Each soil slice at each monitoring site will be calibrated to enable using the Miller Method. This procedure will be run either upon installation, or when the soil horizon reaches sufficient dryness to apply the method.

   a. Soil samples from psychrometer installation (see Box III.F.l.a.v, Step 9) are used to calibrate soils according to the Miller Method. For periodic monitoring, soil water content on a weight basis will be calculated from the psychrometric measurements using the curve obtained for that soil horizon during the Miller Method calibration.

      i. The water potential of the soil sample for calibration will be determined under constant temperature conditions in the laboratory using replicate psychrometer measurements (n=3). The soil sample and psychrometer system will be thoroughly

$$Y \text{ int} = XM\left(X \text{ int}\right) + B$$

equilibrated within a cooler to prevent temperature gradients from influencing the measurements. This method is described in Box III.E.3.a.i.

BOX III.F.3.a.i MILLER METHOD CALIBRATION

STEP 1: Unseal the soil can lid containing the soil sample from Step 9 of Box III.E.l.a.v.
STEP 2: Replace the can lid with a lid through which three soil psychrometers have been passed. Bury the psychrometers in three separate locations toward the center of the soil mass.
STEP 3: Reseal the zip-closure plastic bag and reinforce the bag with electrical tape around the exiting leads of the psychrometers.
STEP 4: Reseal around the soil can with electrical tape.
STEP 5: Place the instrumented soil can into a double-insulated cooler which also contains urethane foam placed to prevent free air movement.
STEP 6: Pack urethane foam around the psychrometer leads where they exit the cooler box.
STEP 7: Place the cooler in an incubator or in an environment with a diurnal temperature fluctuation of no more than 3° Celsius, and obtain readings after 12 to 24 hours of equilibration.
STEP 8: Correct the microvolt readings for temperature and calculate the water potential for each soil sample using the calibration-generated constant "gamma."
STEP 9: Determine the average value for water potential using the data generated by the three psychrometers.

ii. Following measurement of soil water potential, the weight water content of the calibration sample will be determined gravimetrically for the same soil mass.

iii. Slopes and y-intercept values describing a soil water characteristic function will be calculated from the paired water potential, and content determined for each soil slice during calibration. The slopes and intercepts will be calculated according to formulae provided in Sorenson and others (1989), as shown in Box III.F.2.

b. Volumetric soil water content is needed by the monitoring system in order to project the available water. This is calculated from weight water content using the bulk density determined following psychrometers implant.

$$qv = rbqw$$

Where 2v = water content by volume
Db = bulk density
2w = water content by weight

Bulk density will be determined for the depth of the implanted psychrometers by obtaining a volumetric soil sample (Step 7 of Box III.F.l.a.v). The bulk density will be calculated using the sample dry weight that has been determined following over drying at 110° Celsius.

4. Measuring Soil Water Potential in the Field

Psychrometer and piezometer measurements will be collected monthly.

a. Psychrometers at each monitoring site will be read monthly and these data will be used to calculate soil water potential, weight and volumetric water content, and available soil water.

i. The psychrometer data will be screened following each measurement to determine if the sensors are malfunctioning and to eliminate any aberrant data from the records used to project plant-available soil water. A technique for screening Psychrometer data is described in Box III.F.4.a.i.

BOX III.F.4.a.i

SCREENING PSYCHROMETER DATA

Under field conditions, soil psychrometers occasionally malfunction. Three sensors were implanted at each depth to provide backup, as well as to provide the statistic that would permit detection of aberrant data. The data base accumulated during the first nine months of monitoring was analyzed to determine the coefficient of variance (cv) for the mean of triplets of psychrometers. A relationship between maximum observed cv was fitted as an exponential

relationship to mean water potential. The curve with the least error was chosen as the relationship to screen the data. This curve was obtained using December 1988 monitoring data and represents the most stringent existing relationship for screening the psychrometer data. All of the monthly monitoring data must be screened following these steps:
STEP 1: Calculate the mean and standard deviation for each of the psychrometer triplets. These data are the water potentials of the field soils corrected for temperature.
STEP 2: Calculate the cv by dividing the standard deviation by the mean and multiplying the result by 100.
STEP 3: Compare the cv for each psychrometer triplet to the selected curve (the December curve) using the mean water potential as input. If the cv is less than the December curve, then the program accepts all three psychrometers. If the cv for the water potential measurement is greater than the December curve, the program drops the psychrometer datum which has the greatest absolute error from the mean.
The curve selected to screen the data is:

$$cv = e^{(3.45+0.0541*\text{mean water potential in bars})}$$

ii. At least two properly functioning psychrometers will be maintained at each monitoring depth at each monitoring site. When less than two psychrometers are judged to be functional, the cassette will be replaced within two months.

b. The depth to water in each piezometer located at each,monitoring site*will be read on the same day that the psychrometers are read.

The recorded depth to water will be made with reference to the ground level unless otherwise noted.

c. Neutron probe data are being collected to provide a base for future statistical analyses of soil water content. Neutron"probe readings will be taken at least during the months of March, June, and October, but may be obtained more often if necessary. Readings will be taken every 10 cm down the soil profile.

G. Projecting Seasonal Water Balances for Plant Available Soil Water and Transpiration Requirements

The ultimate objective for soil water monitoring is to determine the amount of plant-available soil water. For this comparison, plant water requirements projected in Section III.E are compared to plant-available soil water that is calculated in this section, using the soil-water relationships and techniques presented in Section III.F.

Knowing the tolerance ranges of the species occurring on the monitoring sites is crucial to the ability to predict plant responses to dry conditions. For each species, the soil water potential (which limits the plant's survivability) must be determined experimentally. A number of techniques exist for such experiments, some of which have been applied during the Cooperative Studies. Limiting soil water potentials obtained from previous experiments, such as Dileanis and Groeneveld (1989), are being utilized to establish the limits currently in use. The limiting water potential can be converted to soil water content. The soil water that is present in excess of the limit is taken to be water available for plant consumption.

The distribution of root density and the maximal depth of root growth are important considerations for projecting plant-water availability. Roots of Owens Valley species have been found to decrease exponentially with depth (Groeneveld, 1986), and to also have a mathematically predictable maximum effective depth. The findings from this work have been used to interpret field data to derive empirical relationships that (1) adjust the limiting water potentials with depth, and (2) establish a depth limit for maximum effective rooting, below which soil water is unavailable.

1. Establishing Absolute Limits for Soil Water Potential

Each of the abundant perennial plant species at the monitoring sites will have their absolute limiting soil water potentials determined under laboratory conditions. This limit establishes the lowermost water potential below which a plant cannot extract soil water. It may be determined by either of two techniques.

a. Gradual Soil Drying

This technique is performed under controlled conditions in a greenhouse. Replicate specimens of each species are grown in pots equipped with soil psychrometers implanted within the root mass. The pots are sealed inside plastic bags so that the only escape for water is via transpiration. The bags are opened periodically to provide oxygen for root respiration. The soil water potential is evaluated as the plant gradually succumbs to water stress. The absolute limit is reached when the soil water potential has reached a plateau contemporarily with the death of the plant.

b. Pressure Volume Curve

This technique follows descriptions in Dileanis and Groeneveld (1989) and requires the establishment of a pressure-volume curve for each sample evaluated (Richter, 1978); Tyree and Hammel, 1972). The plant material will consist of shoots of each species gathered before dawn. Initial osmotic potential and initial pressure potential are extrapolated from the pressure-volume curve for each sample. These values are then plotted to yield a lower limiting water potential curve.

2. Best Available Limiting Water Potentials

The best available absolute limiting water potentials for five species which inhabit the Valley floor are presented in Table III.G.2. These data were generated by gradual drying in a greenhouse environment with methods which differed from those noted in Section III.G.1.a above, and by pressure-volume curve techniques as described in Dileanis and Groeneveld (1989).

TABLE III.G.2

ABSOLUTE LIMITING WATER POTENTIALS ESTABLISHED FOR FIVE VALLEY-FLOOR SPECIES

(Inyo County Water Department. data on file)

SPECIES	LIMITING pF	EQUIVALENT POTENTIAL (MPa)	SOURCE
Atriplex torreyi	4.66	-4.5	(1)
	4.71	-5.0	(2)
Chrysothamnus nauseosus	4.41	-2.5	(1)
	4.44	-2.7	(2)
Sarcobatus vermiculatus	4.66	-4.5	(1)
Artemisia tridentata	4.46	-2.8	(1)
Distichlis spicata	4.68	-4.7	(2)

(1) pressure-volume curves
(2) gradual,drying

3. Two Values for Limiting Water Potential

Pending further research, two limiting values of water potential have been adopted using the data from Table III.G.2. These limits are presented in Table III.G.3. A study is presently under way (as of April 1990) to test existing limits for known species, or to establish these limits for new species, using the gradual drying method. Eight species will be studied: *Atriplex torreyi, A. canescens, A. confertifolia, Artemisia tridentata, Sarcobatus vermiculatus, Chrysothamnus nauseosus, Distichlis spicata,* and *Sporobolus airoides*.

TABLE III.G.3

LIMITING VALUES FOR SOIL WATER ABSORPTION BY OWENS VALLEY-FLOOR SPECIES

Limit I	-- pF = 4.4 -- for Asteraceae shrubs *Chrysothamnus nauseous* *Artemisia tridentata*
Limits 2 and 3	-- pF = 4.7 -- for Chenopod shrubs and the two abundant Owens Valley grasses *Atriplex torreyi* *Sarcobatus vermiculatus* *Distichlis spicata* *Sporobolus airoides*

4. The Role of Rooting for Soil Water Extraction

Depth and density of rooting are important for determining the available soil water and maximal depth for water extraction. (Note: Additional rooting data is under analysis at this time; therefore, relationships presented here are subject to revision.)

a. Maximum effective depth of rooting (MED) will be determined for shrubs and grasses, separately, using field studies on sites where the water table has been drawn down by pumping. The MED will be determined by statistically modeling root density (length per unit volume) versus depth using the data from volumetric samples extracted by augering. The concept for MED is that even though root growth may occur below this depth, because of limited density, the role for uptake may be negligible. Best available information (per April 1990) indicates that MED for shrubs is 3.7 m and for grasses, around 2 m. Therefore, the top two meters has been chosen to be the rooting domain for grasses, and four-meters deep has been chosen for shrubs.

Figure III.G.4.a. presents a graphic representation of the technique for determining MED on shrub species. For interpreting MED, future work will also attempt to correlate root density with the depthwise curve of pF.

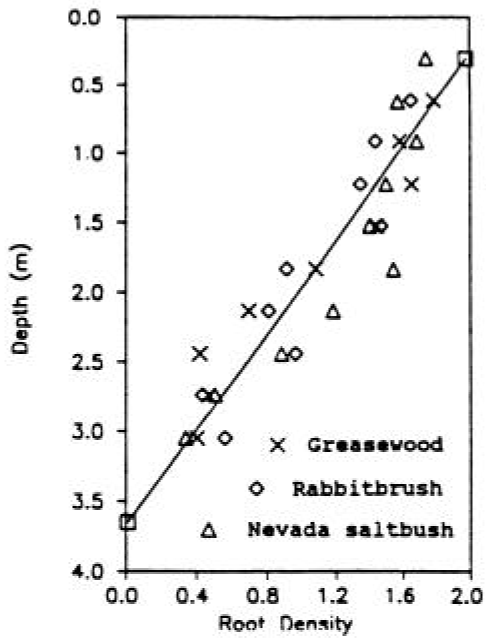


FIGURE III.G.4.a

Graph showing log-linear decrease of root density with depth. These data were obtained at a study location near Independence during January 1987 for the Cooperative Studies. The water table had been artificially lowered from about 1 m deep to approximately 5 m deep over the previous three years. From this data, the maximum effective rooting depth (MED) is at 3.7 m, where the line crosses the y-axis.

b. For Owens Valley-floor plant species, root density has been found to decrease with depth as an exponential function. Because the hydraulic conductivity of soil decreases exponentially as soil water content diminishes, the decreasing root density with depth prevents extraction of the water in the bulk soil down to the absolute limit. The actual amount that can be extracted can be determined empirically as a function of root distribution with depth. Existing data provided a relationship for decrementing the limiting pF for each meter slice of soil (see Figure III.G.4.b). The depthwise values for limits one, two, and three decremented using this relationship are presented in Table III.G.4.b.

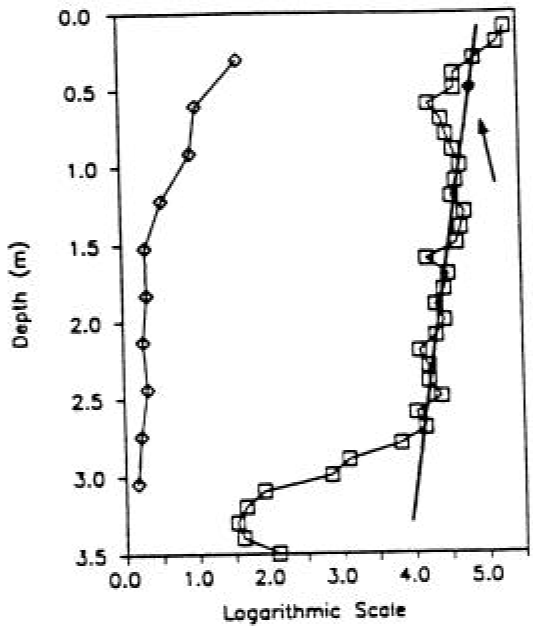


FIGURE III.G.4.b

Relationship used for decrementing soil water limits with depth. On the graph are plotted depthwise distribution of limiting water potential (as pF) expressed as squares and root density expressed as diamonds. The data were obtained at a study location near Bishop which had the water table artificially lowered during the previous 3 years. The line that is superimposed on the pF data has been used for decrementing limiting pF with depth. The point indicated by the arrow is Limit 2 (pF of 4.7) which corresponds to the dominant vegetation growing at the location. The lower pF values deeper in the profile correspond to capillarity from the water table at 3.7 m.

TABLE III.G.4.b

DEPTHWISE VALUES FOR LIMITS 1 AND 2 DECREMENTED BY THE RELATIONSHIP IN FIGURE III.G.4.b

DEPTH	LIMIT I		LIMIT 2		LIMIT 3	
SLICE	PF	MPa	pF	MPa	pF	MPa
1 m	4.4	-2.45	4.7	-4.90	4.7	-4.90
2 m	4.1	-1.23	4.4	-2.46	4.4	-2.46
3 m	3.9	-0.78	4.2	-1.55	--	--
4 m	3.6	-0.39	4.0	-0.99	--	--

5. Calculating the Plant-available Soil Water Content (abbreviated AWC)

AWC is calculated at monitoring sites to project the soil-to-plant water balance.

a. The AWC at each monitoring site shall be projected for the dominant and co-dominant cover. Because all of the plants on a site are sharing the same soil water, transpiration from all species shall be projected at the limiting water potentials appropriate for the most sensitive dominant and/or co-dominant species.

b. Determining Limiting Water Content (LWC)

The "Miller Method" will be used to calculate the LWC on a weight basis according to the depthwise limiting soil water potentials. The "Miller Method" calibration data will be used for this calculation. To perform this calculation, the slope and y-intercept of the line determined during calibration (Sections III.F.2 and III.F.3) are used to calculate the water content for the appropriate depthwise limit as presented in Table III.G.4.b.

$$q_w = \frac{a - pFlim}{b}$$

where: pFlim = limiting pF
b = slope
a = y intercept

c. The AWC will be computed on a per-meter depth-slice basis to compare the limiting water contents by the Miller Curve technique for each meter slice of soil.

where pFmeasured = value calculated from monthly reading

$$q_{AWC} = \frac{a - pFmeasured}{b}$$

The depthwise limiting water potentials will be used to calculate a limiting weight water content for each meter slice which will be subtracted from the weight water content calculated using the characteristic function and data obtained from the in situ psychrometers. For the purpose of monitoring and estimation, the result of this calculation is taken as representative of the available water for the 1 m slice of soil in which the psychrometers reside. The calculation is shown graphically in Figure III.G.S.c.

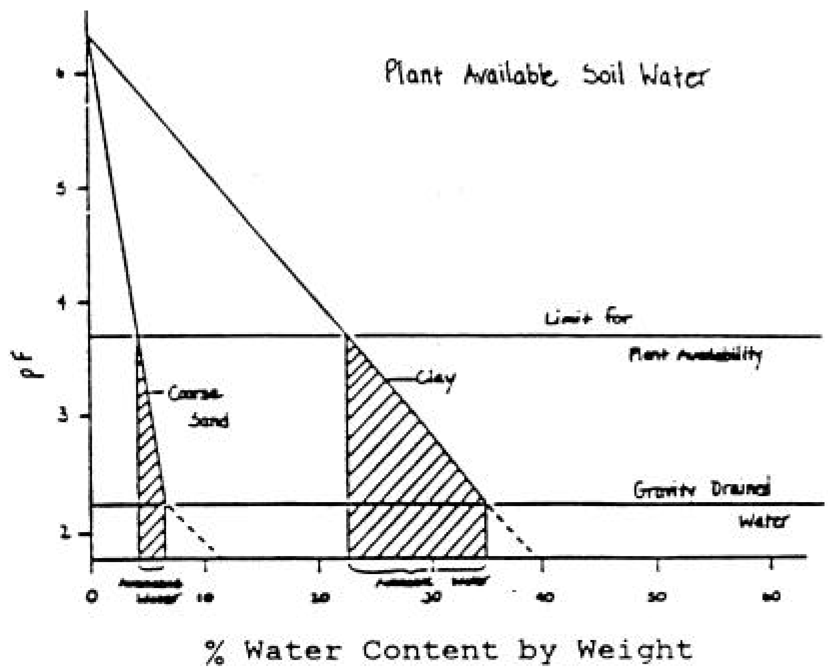


FIGURE III.G.5.c

Graph depicting the use of the "Miller Method" for calculating plant-available water. The plant-available limit was set at pF = 3.7 for this example. The calibration procedure sets the linear relationship to be used for the characteristic function, and the plant limit sets the upper bound along the line. Soil water contents measured in the field along any point on the line below the limiting value describe the plant-available water in that soil slice. Note that coarse textured soils yield much less water for a given change in pF than do finer textured soils.

d. Volumetric soil water content will be calculated from the weight water content by multiplying by the bulk density obtained during calibration as described under III.F.3.b.

e. The AWC will be determined by summing the individual AWC for the meter-slices of soil representing the appropriate rooting zone. For grasses, this will be the upper two meters. For shrubs, this will be 4.0 meters deep. This is under analysis.

6. Projecting Water Balance Through a Growing Season

The species-wise transpiration curves combined with leaf area will be used to project transpiration for a full or partial growing season (Section III.D.l.c). This plant requirement is then subtracted from the available soil water computed as the sum for all depth slices within the rooting zone. Precipitation is incremented to available soil water for projecting soil-to-plant water balance according to the Agreement.

a. For projecting the soil-to-plant water balance for the following growing season using March psychrometric data, estimates of plant-water requirements will be based on vegetation data collected during the previous growing season.

No precipitation will be incremented to the calculation of water balance when made for the growing season during the same calendar year.

b. When projecting the soil-to-plant water balance for the remainder of the growing season, the most current vegetation measurements will be used and the integration of the linked polynomial curves will be between the times taken to represent the mid-season peak (DOY is 186) and leaf drop (DOY is 289). The resultant plant-water requirement will be compared to the estimation of available water. No precipitation will be incremented to the calculation.

c. For soil-to-plant water balance projections made during October for the following growing season, plant-water requirements will be apportioned by the curves which governed plant-water requirements through the summer growing season just completed. The AWC for this calculation will be the AWC from the most current psychrometer readings, with an increment added to represent half of the average annual precipitation. The precipitation amount used is the quadrangle average precipitation from isohyetal maps (LADWP, 1976). The one-half precipitation figure represents the amount of water projected to be available to plants since approximately half of the average annual precipitation is lost through evaporation (Groeneveld, 1989).

The amount of precipitation that is credited to the October calculations will be reduced during periods of drought according to the scheme shown in Table III.G.6.c.

TABLE III.G.6.c

SCHEME FOR DECREMENTING ADDED PRECIPITATION DURING DROUGHT PERIODS

ADDED PRECIPITATION	CONDITIONS
40%	If the previous year's run off and current year's projection are less than 70% of average
30%	If the two previous year's runoff and the forecasted runoff are less than 75% of average

IV. HYDROLOGIC MANAGEMENT

This section outlines the procedures that will be followed in the monitoring and evaluation of hydrologic data. Effects on private wells, the procedures for locating and operating new wells, and the methods of determining groundwater mining are described. Prior to presenting the specific issues contained in this section, some of the basic techniques of hydrologic analysis are discussed.

The hydrologic data that will be analyzed by both LADWP and Inyo County include depth to water data in approximately 700 monitoring wells; water levels and pumping data in approximately 100 pump-equipped wells; flow data from various streams and canals; precipitation data; and water use data on LADWP-owned land. Most of these data are collected monthly. Some depth-to-water data is collected less frequently—especially outside of well fields-but it is collected at least twice per year. Historical hydrologic data that has been collected by LADWP is contained in reports entitled "Monthly Well Report" and "Totals and Means Report."

Some of these basic data will be summarized in the form of hydrographs (time series plots of the data) in order to regularly identify trends and evaluate conditions qualitatively. More detailed, quantitative analyses of portions of the data will be performed under certain specific conditions described below. Independent quantitative analyses will also be performed by either the County or LADWP as conditions or circumstances warrant.

Specific techniques are sometimes used in an attempt to analyze and quantify a cause-and-effect relationship that has been inferred from a qualitative evaluation of the data (i.e., a trend is observed in the data that corresponds to an identified cause). For example, the decline in the water level in a well can be caused by groundwater pumping, by decreased recharge to an area, or by both. Therefore, the qualitative interpretation of a hydrograph that shows a declining water level during a period of high pumping and low recharge is that both factors are affecting the water level in the well. Quantitative analysis is necessary to separate the effects of the individual causes. Three types of commonly used quantitative analysis are briefly described in this section: regression analysis, analytical modeling, and numerical modeling.

Regression analysis relies on the defining of the process under investigation through a statistical analysis of the data. The result of a regression analysis of groundwater levels in a specific well would provide an equation that predicts the groundwater level in a specific well, given the pumping and recharge in a given well field. One result of this type of equation is the ability to separate the effects of drought and pumping. Regression analysis is a tool that should be used cautiously due to its empirical nature.

Analytical and numerical modeling of a hydrologic system represents a physically based approach to analyze and quantify cause-and-effect relationships. Both techniques rely on physically based equations that mathematically describe groundwater flow. The results of these approaches include estimates of groundwater level, change in groundwater level (drawdown or recovery without regard to specific starting or ending level), and flow (either as spring flow or subsurface flow). Basic input to either approach includes numerical values that describe the aquifer system (e.g., transmissivity, storativity, leakance), quantification of recharge and pumping, and mathematically describing the boundary conditions of the flow system under investigation.

The basic difference between analytical and numerical modeling is in the types of assumptions that are necessary to describe the hydrologic system in terms of mathematical equations. In general, while analytical methods are more easily implemented, they are also more restrictive, in terms of simplifying assumptions, than are numerical methods. The decision to choose one method over the other is generally based on data availability (numerical models require large amounts of data), and on the type of analysis (simple versus complex relationships). Analytical methods are generally better suited to investigations of relatively simple relationships (e.g., predicting the drawdown in a well due to the pumping of a limited number of wells at a constant rate), while numerical methods are better suited to investigating complex relationships (e.g., the regional response of water levels under varying amounts of pumping and recharge). In all instances, at least some input data must be estimated, and the results interpreted in light of the assumptions and limitations of the particular modeling approach.

The most notable example of an application of numerical techniques in the Owens Valley, to date, and one of the principal tools that will be used in the future for hydrologic analyses, is the groundwater flow models that have been developed by the U.S. Geological Survey, Inyo County, and LADWP. These models were developed and calibrated as part of the groundwater studies from 1985 to 1988, and represent the most comprehensive description of the hydrologic system of the Owens Valley. The U.S. Geological Survey model covers the entire Valley, the northern half of the Valley was modeled by Inyo, and the southern half was modeled by LADWP. All models were developed in conjunction with the others and, where the areas overlap, all provide similar results. Details of the models are contained in reports that are available at the Inyo County Water Department and LADWP offices.

The Inyo and LADWP models were used to develop the 10-foot drawdown contours that are depicted on the vegetation management maps. These contours were developed by running the models under assumed worst-case scenario conditions (all existing wells pumping with recharge conditions of April 1977 to March 1978 repeated three consecutive years). The area within the contours represents the area that could potentially be impacted by pumping, and vegetation soil monitoring networks were subsequently established partially on the basis of these results.

A. Private Wells

Monitoring to protect private wells will be conducted at existing and/or newly installed monitoring wells. The data from these monitoring wells, along with other hydrologic analyses, will be used to attempt to separate the effects of drought, private pumping, and LADWP pumping on groundwater levels.

Shallow monitoring wells will be installed in the Valley as necessary to determine whether groundwater pumping by LADWP will affect water levels in private wells.

1. Determining whether an impact on a private well is attributable to groundwater pumping by LADWP.

   Hydrologic analyses will be conducted to determine whether the lowering of the water level in a private well is attributable to groundwater pumping by LADWP. These analyses will include the performance of aquifer tests where necessary, site-specific analytical or numerical modeling, and running the groundwater flow model of the area in question. Due to the inherent assumptions and limitations of the groundwater models, they will be used only to identify areas of potential concern. The models were developed to evaluate long-term and regional effects of pumping. Private wells were not included in the models because of the cyclic nature of their operation and their generally low production rates. Therefore, groundwater models will be used to identify potential areas of concern and more site-specific techniques will be applied, such as installation of monitoring wells, to project and avoid potential problems.

   a. Aquifer test will be conducted at all LADWP wells located near private wells if sufficient aquifer characteristic data do not already exist for the area.

   b. The Technical Group will initiate site-specific analytical or numerical models to evaluate the response of private wells to pumping and drought. Groundwater levels will be measured at monitoring wells drilled to depths similar to the nearby private wells. The data collected from these sites will be used to track the response of groundwater levels in the area due to the effects of drought, private pumping, and LADWP pumping.

2. Determining whether an impact on a private well is significant

In determining if increased pumping by LADWP is causing a significant impact on private wells, the following factors will be considered:

a. Amount of water table decline attributable to LADWP pumping.

b. Decreases in flow rates from private wells attributable to LADWP pumping.

c. Amount of additional pump lift required as a result of water table lowering caused by LADWP pumping.

3. Mitigating impacts to private wells

Any significant impacts on private wells will be promptly mitigated by LADWP such that the impact is reduced to a less than significant level in a manner that is fair and equitable to the owner of the private well. Examples of mitigation include the following:

a. Discontinue pumping LADWP wells to allow water level recovery in the vicinity of the impacted private well.

b. Setting the pump deeper in the casing of the private well.

c. Deepening or replacing the private well.

d. Compensation for additional power cost if water table decline requires significant increase in pump lift.

B. Guidelines for Drilling and Activating New Production Wells

As provided in Section VI of the Agreement, the Department may replace existing wells and construct new wells in areas where hydrogeologic conditions are favorable, and where the operation of the wells will not cause a significant change in vegetation that would be inconsistent with the goals and principles of the Agreement. The guidelines that will be followed when constructing and putting new wells into operation are set forth in this section.

1. Evaluation of Potential Impacts

The potential impact of operating new wells will be evaluated by the Inyo/Los Angeles Technical Group as follows:

a. Developing Site Hydrogeologic Information

i. Reviewing existing nearby well logs, borehole logs, well test reports, water level data, and pumping data.

ii. If available, running the appropriate groundwater flow model with all existing wells and the new well(s) pumping during a simulated worst-case, three-year drought (hydrologic conditions of runoff year 1977-78, which is the driest on record, repeated three times) to identify the areas with the greatest potential for surface effects due to pumping (area of 10 feet or greater drawdown).

iii. Drilling one or more test holes if water level data is not adequate or not available.

b. Affected Vegetation Condition

Inventorying and classifying the vegetation that could be affected by operation of the well (use vegetation inventories that reflect conditions from 1984 to 1987).

   i. Identifying vegetation that has the greatest chance of being adversely impacted by pumping (the area where drawdown is greater than or equal to 10 feet).
   ii. Identifying new sites for monitoring vegetation, soil moisture, and water level as necessary.

c. Identification and assessment of other potential significant effects on the environment:
   i. Springs (e.g., reduced flow resulting in significantly less water available to surrounding vegetation).
   ii. Flowing wells (e.g., reduced flow resulting in significantly less water available to surrounding vegetation).
   iii. Private wells (e.g., lowered water levels resulting in significantly increased pumping costs and/or impairment of operation).

2. Construction and Testing

   a. LADWP will design, schedule, and contract for optimally designed wells considering location, economics, and current practice in the industry.

   b. Inyo County shall apply for and obtain any well construction permits required by the County.

   c. Aquifer test
      i. A constant flow rate aquifer test (up to 72 hours duration) will be conducted on each new well. The Technical Group will determine the length. of the aquifer test.
      ii. A minimum of one monitoring well is required for the test. The Technical Group will determine whether existing monitoring wells are adequate, or whether there is a need to construct a new monitoring well.
      iii. All well and test data will be shared by Inyo County and LADWP.

3. New Well Areas

   a. Only one well shall initially be constructed and operated in any new area.

   b. Water level and vegetation monitoringWater levels and vegetation shall be monitored as agreed to by the Technical Group. Additional monitoring wells may be required.

   c. Monitoring to evaluate for any potential effects of the operation of the new well or wells shall be performed. This may require installation of monitoring wells which will be constructed at the same time as the production well.

   d. No additional well(s) shall be installed in the area until an initial well has been operated for at least six (6) months at full operational capacity.

C. Determining Existence of Groundwater Mining

One of the goals of the Inyo/Los Angeles Agreement on a Long-term Groundwater Management Plan is to avoid long-term groundwater mining in the Owens Valley. The method that has been established to meet this goal is management of groundwater pumping, so that the total pumping from any well field over a 20-year period (the current year plus the 19 previous years) does not exceed the total recharge to the same well field area over the same period. The Technical Group may increase the annual pumping from a well field area above this amount if a recharge program for that area is implemented, or for other relevant reasons that are consistent with the goals and principles of the Agreement.

1. Background and Definition

This section of the Green Book presents information related to the general subject of groundwater mining; presents and discusses the definition of groundwater mining as used in the Agreement; presents the details of the recharge calculations that will be performed; discusses the concept of well field areas and how the calculated recharge is apportioned to the identified areas; and presents the procedures related to the management of groundwater pumping that will be used to ensure that pumping will not exceed recharge in accordance with the Agreement.

The concept of groundwater mining is rather subjective, and no consistent definition exists. J. H. Feth, of the U.S. Geological Survey (USGS), provides a description and review of the use of the term in an article that appeared in a USGS publication (WRD Bulletin, January 1982, on file with the Inyo County Water Department). The article provided a foundation that was used to develop a definition for the Inyo/Los Angeles Agreement that was both technically accurate and acceptable to the public's desire to have a consistent definition that could be easily applied and understood, and that would prevent depletion of the groundwater resources of the Owens Valley.

Feth's main point in the article is that the term "groundwater mining," if used, should be defined. The proposed Agreement provides such a definition by stating what is to be avoided: "managing annual groundwater pumping so that the total pumping from any wellfield over a 20-year period does not exceed the total recharge to the same well field area over the same 20-year period." Clearly, the intent of the groundwater mining provision of the proposed Agreement is to prevent long-term depletion of groundwater storage.

Feth summarizes several definitions of groundwater mining, many of which include the comparison of pumping and recharge. Many of the definitions also include the use of actual groundwater level data. While it is not explicitly stated in the proposed Agreement, the monitoring and interpretation of groundwater level data in all wells is an important aspect of protection of vegetation and of the groundwater resource. Inherent difficulties in application and interpretation of actual groundwater level data prevents their effective use with a "formula" approach to prevent groundwater mining in the Owens Valley. The evaluation of these data will serve as a check as to the accuracy of the recharge estimates that have been and will be made.

Avoidance of groundwater mining does not provide protection to the vegetation. Provisions for vegetation protection are contained in other sections of the Agreement. The intent of this provision is to avoid long-term depletion of groundwater storage.

Storage is depleted any time a well is on, whether the well belongs to DWP or a private domestic user. Storage will be depleted to an even greater extent when pumping continues during a drought period. Storage is replenished, however, in a short time period when the private domestic well is turned off, and over a longer period when DWP turns its wells off during wet years. As long as the long-term pumping does not exceed the long-term recharge, no mining is occurring.

Another point that needs to be emphasized is that the definition that is included in the Inyo/Los Angeles Agreement 'provides for the avoidance of mining by requiring the adjustment of pumping amounts if it is clear that pumping will exceed recharge. The relatively simple formula approach allows for an easy determination of this possibility, and immediate steps to correct the situation can be implemented before mining actually is occurring.

In addition, it should be noted that the concept of groundwater mining is distinct from the concept of safe yield of a groundwater basin. The concept of groundwater mining deals only with a permanent depletion of storage of groundwater. The concept of safe yield, however, involves factors and issues that involve placing values - economic and noneconomic - on either the use of groundwater (in the case of the Owens Valley, for example, the use by native vegetation versus pumping by export), or the effects of groundwater development (in the case of the Owens Valley, for example, the adverse effects of DWP pumping on other groundwater users in the Owens Valley). Per the Inyo/Los Angeles Agreement, safe yield in the Owens Valley can be defined as the amount of groundwater that can be extracted without any adverse effect on the environment or on other users of groundwater. it can be seen that a given average amount of pumping over several years could either result in impacts or have no impacts depending upon how that groundwater was pumped, both spatially and temporally.

While the Inyo/Los Angeles Agreement does not establish a set quantity of pumping (except for the Bishop Cone), the environmental standards set forth define "safe yield." Indeed, it is commonly accepted among hydrologists that, given the myriad of competing values that are involved in defining a quantity of safe yield, a single average quantity cannot be adequately defined. The Inyo/Los Angeles Agreement is in accord with this accepted practice by placing more faith in monitoring data to dynamically define safe yield rather than establishing set amounts of pumping that would ostensibly prevent all undesirable effects.

2. Calculation of Groundwater Recharge

The current method used to compute a recharge value for each well field relies on information obtained from the USGS relevant to its computer model of the Owens Valley (Wes Danskin, written communication, 1989). Using water years (October to September) as the basis for calculations, yearly numerical values are obtained for each source of recharge to the aquifer system in the Owens Valley in each well field. The described method is illustrated herein using data for water years 1969 through 1989.

Eight sources are considered when calculating recharge in the Owens Valley. These are: streams, ungaged intermountain slopes, canals, groundwater recharge, underflow, irrigation and livestock, precipitation, and lakes and reservoirs. The following paragraphs explain the procedure for calculating the individual source values.

Streams

Recharge to groundwater occurring in each stream is calculated as a function of gage readings, channel characteristics, evaporation, and vegetative covering by using equation (1) below:

(1):

$$R_{ij} = \left(BOM_i * RO_j * SRR_i\right) * \left(1 + SRA_i + SRB_i\right) - SL_i * SW_i * SET_i * VC_i$$

where: i = Stream index
j = Year index
R_{ij} = Recharge in stream i during year j[L^3/T]
BOM_i = Average flow at base of mountain station for stream i (if no gage, represents where stream enters the Valley fill) [L^3/T]
RO_j = Ratio of annual Valley-wide runoff to long-term average Valley-wide runoff for year j
SRR_i = Ratio of stream loss to BOM. for stream i
SRA_i = Fractional increase in stream length above station for stream i
SRB_i = Fractional increase in stream length below station for stream i
SL_i = Length of stream i [L]
SW_i = Width of stream i [L]
SET_i = Annual evaporation from area near stream channel for stream i [L/T]
VC_i = Fraction of area near stream channel covered by vegetation for stream i

Table 1 (Appendix B) provides the values for BOM, SRR, SRA, SRB, SL, SW, SET, and VC for each stream included in the analysis, while Table 2 (Appendix B) gives the values for RO for water years 1969 through 1989. In addition, Table 3 (Appendix B) provides the calculated stream recharge values in acre feet per year for water years 1969 through 1989.

Ungaged Intermountain Slopes

Recharge to groundwater due to runoff that infiltrates in areas without defined channels is calculated using equation (2) below:

(2):

$$R_{ij} = UR_i * RO_j$$

where: i = Intermountain slope index
j = Year index
R_{ij} = Recharge in intermountain slope area i in year j $[L^3/T]$
UR_i = Long-term average ungaged recharge for slope i $[L^3/T]$
RO_j = Ratio of annual Valley-wide runoff to j long-term average Valley-wide runoff for year j

Table 4 (Appendix B) lists the UR values for each ungaged intermountain slope included in the analysis, while Table 5 (Appendix B) provides the calculated recharge in acre feet per year for water years 1969 through 1989.

Canals

Two categories of canal recharge-spillgates and canals-are used. A time averaged value for each canal component is used for each year it is in use. For spillgates, the following equation (3) is used:

(3):

$$R_{ij} = SGD_{ij} * SGR_i$$

$$R_{ij} = \frac{CR_i \text{ for } j \text{ in set } J_i}{O \text{ for } j \text{ not in set } J_i}$$

where: i = Spillgate index
j = Year index
R_{ij} = Recharge in spillgate area i in year j $[L^3/T]$
SGD_{ij} = Discharge at spillgate i in year j, either an average annual or actual annual value dependent upon j $[L^3/T]$
SCR_i = Average annual recharge rate in spillgate area for spillgate i

Table 6 (Appendix B) lists the values for SGD and SGR, as well as the calculated annual recharge rate for each spillgate. Average annual values for SGD are generated for water years 1969 through 1986, while an actual annual SGD for each spillgate is used beginning in water year 1987.

The canals considered have an estimated recharge rate which remains constant for each year it is active. Zero recharge occurs when a canal is not in use. Equation (4) is used to determine recharge by:

(4):

where: i = Canal index
j = Year index

J_i = Set of years in which canal i is in operation
R_{ij} = Recharge in canal i in year j [L^3/T]
CR_i = Average estimated canal recharge for canal i [L^3/T]

Table 7 (Appendix B) lists the values for CR, the years comprising set J, and the calculated recharge for each canal considered. In future years, an updating of set J based on the actual operation of the canals is required.

Groundwater Recharge Areas

Areas in which water is allocated for groundwater recharge are included in the calculations labeled under this section. There are three formulas used for calculation, one being the general format with two noted exceptions. For all but the two cases described below, recharge is calculated by using equation (5).

(5):

$$R_{ij} = RR_i * AL_i * LADWP_{ij}$$

where: i = Recharge area index
j = Year index
R_{ij} = Recharge in area i in year j [L^3/T]
RR_i = Recharge rate for recharge area i
AL_i = Fraction of water allocated to area i compared to total allocation
$LADWP_{ij}$ = Estimated annual quantity of water allocated to general areas of Owens Valley for a particular use (see Russ Rawson of LADWP)

Table 8 (Appendix B) provides the values for RR, AL, and the applicable area used for LADWP for each recharge area. Table 9 (Appendix B) provides the values for LADWP for each area for water years 1971 through 1989. The computations leading to Table 9 (Appendix B) are not available prior to 1971; therefore, an alternative method was used to estimate the values for years 1969 And 1970 (see Wes Danskin of USGS).

For the Blackrock/Thibaut Areas 1, 2, and 3, equation (6), a modification of equation (5), is used, so that:

(6):

For RO_j greater than 1.25:

$$R_{ij} = RR_i * AL_i * MIN\left[MAX\left(0, LADWP_{ij} - C_1\right), C_2\right]$$

For RO_j less than or equal to 1.25:

$$R_{ij} = 0$$

where: C_1 = 6444 ac.ft.
C_2 = 50 cfs
RO_j = Ratio of annual Valley-wide runoff to long-term average Valley-wide runoff
MAX = Maximum function
MIN = Minimum function

R_{ij} RR_i AL_i, and $LADWP_{ij}$ are described in equation (5).

For Indian lands, equation (5) is reduced to equation (7) below:

(7):

$$R_{ij} = RR_i * LADWP_{ij}$$

where: R_{ij}, RR_i, and $LADWP_{ij}$ are described above in equation (5)

Table 10 (Appendix B) provides the calculated recharge values for water years 1969 through 1989 for each recharge area listed on Table 8 (Appendix B).

Underflow, Irrigation and Livestock, Precipitation, Lakes and Reservoirs

Estimates for the average volume of recharge per year for underflow, irrigation and livestock, precipitation, and lake and reservoir components were obtained from the USGS Open-File Report 88-715, 1989. These values—averages based on water years 1970 through 1984--are as follows:

Underflow	4000 acre-feet per year
Irrigation and Livestock	10000 acre-feet per year
Precipitation	2000 acre-feet per year
Lake and Reservoir	1000 acre-feet per year

Once the well field areas have been delineated, the values above are apportioned amongst them in an appropriate fashion.

3. Calculation of Annual Recharge by Well Field Area

The following section describes the method used to calculate the yearly recharge in the various Owens Valley well field areas. Well field areas in the Owens Valley have been designated on the basis of an evaluation of groundwater flow patterns which were derived from an analysis of groundwater level data and the results of the groundwater flow models developed by LADWP and Inyo County. At present, six well field areas have been designated: Laws, Bishop, Big Pine, Taboose-Thibaut, Independence-Symmes-Bairs, and Lone Pine.

The northern portion of the Valley was considered as three distinct areas. Groundwater flow in the Bishop area is from west to east, curving to the south in response to the presence of the Owens River. Flow from Laws is from north to south. Big Pine is considered a separate area due to flow patterns, its isolation from the Bishop area, and its separation from the Taboose-Thibaut area by the Poverty Hills, which act as a barrier to groundwater flow.

The southern portion of the Valley is divided into three areas. The Taboose-Thibaut area covers the Taboose-Aberdeen and Thibaut-Sawmill well fields. The fact that these well fields are close together, have no natural hydrologic boundary separating them, and groundwater flow patterns between the well fields change in response to high pumping, suggest that these areas can be treated as one for the purposes of calculating recharge. Of note in this area is the allocation of 50 percent of Oak Creek recharge (stream and ungaged intermountain slope) to this area. High pumping during periods of low runoff and constant pumping at the Blackrock Fish Hatchery have caused a reversal in the pre-1970 gradient in the area south of the hatchery. This results in significant recharge from Oak Creek flowing north into the Thibaut-Sawmill area. Future analysis will attempt to more accurately quantify this component.

The Independence-Symmes-Bairs area covers the Independence-Oak, Symmes-Shepherd, and Bairs-Georges well fields. These well fields have been combined on the basis of groundwater flow patterns in the alluvial fan areas and the proximity of the well fields to one another. The northerly component of groundwater flow in the fan areas suggest that recharge from as far south as Georges Creek can recharge the Independence-Oak well field.

Lone Pine is considered a separate area due to the distance between the wells and the Bairs-Georges well field. In addition, the presence of the Alabama Hills effectively isolates the Lone Pine area.

A net recharge to groundwater for each designated well field area in the Owens Valley is computed by summing the individual components of each source contributing to that well field area. Table 11 (Appendix B) contains the assignment of recharge from streams, ungaged intermountain slopes, canals, and groundwater recharge areas to each well field area; divisions-of underflow, irrigation and livestock, precipitation, and lakes and reservoirs among the well field areas are presented in Table 12 (Appendix B).

Using the above procedure for determining yearly recharge components to each well field area, a net recharge for each area was calculated for each water year in the time period bracketed by 1969 and 1989. Calculated values are given by well field area for water year 1989 in Table 13 (Appendix B). In these calculations, the assumption is made that the average values remain as given above for underflow, irrigation and livestock, precipitation, and lakes and reservoirs. Total calculated recharge by well field for each year indicated above is given in Table 14 (Appendix B), along with the yearly historical pumping values. The official pumping records on a well field basis are found in the LADWP's Monthly Well Report, Book A.

It should be recognized that the recharge estimates and subzone delineations are developed for specific years in 20-year periods. As pumping amounts and patterns change, the amount of recharge and the distribution of hydrologic subzones may change. it will be necessary to analyze total recharge, recharge components, water level changes, and groundwater flow patterns in the future to determine recharge conditions for any future 20-year period in order to determine whether or not long-term groundwater mining is occurring.

4. Procedures for Managing Annual Pumping

The annual pumping program, developed in April in each year, provides a convenient vehicle to address the issue of groundwater mining. The data (runoff, water use, pumping, and groundwater level) for the previous water year (October-September) are complete and in their final form by December which provides the Technical Group sufficient time to thoroughly analyze the groundwater conditions of the Valley, and recommend any necessary modifications to the recharge calculations or well field designations prior to implementing the pumping program for the runoff year.

The use of estimated recharge values, based on runoff estimates for the previous October-March and estimated recharge values for the ensuing April-September period will be used to update the recharge/pumping comparisons into the future, and establish limits on the amount of pumping by well field areas in accordance with the provisions of the Agreement. The review and reporting period for the mining calculations and establishment of limits are, therefore, during the April pumping program.

As discussed previously, the calculation of recharge is a detailed and rigorous exercise. In order to facilitate the calculation in the context of estimating future recharge as part of establishing pumping limits, the use of relatively simple functional relationships between runoff and recharge, derived through regression analysis, will be used. These relationships are:

Laws	455 + (0.976 * (RO**2)) + (387536/RO)
Bishop	16144 + (281 * RO)
Big Pine	584 + (284 * RO)
Taboose-Thibaut	1466 + (342 * RO)
Ind-Sym-Bairs	3475 + (347 * RO)
Lone Pine	3492 + (110 * RO)

where: Recharge amounts in acre-feet/year
RO = Runoff in percent average

Average runoff = 469852 acre-feet/year (calculated for the 49-year period from 1935 to 1984)

These regression equations will have to be reviewed and changed periodically as new data becomes available to reflect changes in operations and well field area boundaries, or the need for distribution of percent average runoff.

The estimate of runoff for the entire Owens River watershed (Long Valley, Long Valley to Tinemaha, and Tinemaha to Haiwee) from the previous October to March period, in acre-feet, will be added to the projected April to September runoff, in acre-feet, to arrive at an estimated October to September runoff. This value will then be divided by 469,852 and multiplied by 100 to arrive at an estimate of runoff in terms of percent of average. This percent average value will then be entered into the above regression equations to arrive at an estimated recharge in each well field area. The fit of these models to actual data are presented on Figures 1 through 6 (Appendix B).

Based on this estimated recharge and the total recharge during the previous 19 years, total recharge for the 20-year period is calculated. The actual pumping from the previous 19½ years is then subtracted from the 20-year recharge to arrive at the pumping limit for the next six months. Calculated values, based on the estimated 1990 water year runoff, are given in Table 14 (Appendix B).

If the difference in recharge and pumping in a well field area is within limits established below (generally the maximum annual production capability of the well field area), provisions will be made in the pumping program that establish limits that are designed to prevent mining during the October to March period of the then-current runoff year, or the subsequent runoff year in the event of a below-average runoff year. It is expected that these limits will be modified as production capacity in each well field area changes.

APPROXIMATE ANNUAL MAXIMUM WELLFIELD PUMPING CAPACITIES

WELL FIELD AREA	ACRE-FEET/YEAR
Laws	38000
Bishop	12000
Big Pine	42000
Taboose-Thibaut	55000
Ind-Sym-Bairs	41000
Lone Pine	2700

In summary, a section of the annual pumping program, developed in April of each year, will include an update on the final calculations of recharge and pumping for the previous 20 water years, and will include a section of the estimated recharge of the then-current water year and pumping limits.

V. FURTHER STUDIES

The scientific effort for gathering data for managing the Owens Valley watershed and its groundwater-dependent plants has been unprecedented in scope. Investigation specifically aimed toward managing the Owens Valley hydro-ecology has been performed from 1983 through present by the U.S. Geological Survey, the USDA Soils Conservation Service, City of Los Angeles Department of Water and Power, and Inyo County Water Department. The results from this work have been incorporated into the Agreement and the Green Book. Even though much has been accomplished, the scale of the Owens Valley, the complexity of the hydro-ecological system, and the potential severity of the consequences of an error in management require continuing intensive effort to ensure that the goals and principles of the Agreement are fully achieved. Therefore, studies concerning monitoring techniques, plant distribution, plant-water relationships, and the linkage between the hydrologic system and groundwater- dependent plants should continue.

This section lists the studies and projects that will be conducted or are being considered by the Technical Group. The pertinent sections in the Green Book are listed for reference.

A. Projects

The projects described below do not require further data gathering and are an adaptation of existing techniques and computer software.

1. Vegetation Management Maps

   Analysis of Vegetation Map Data Base and Refinement, if necessary, of the Vegetation Management Maps (Green Book Section II)

   The data base is currently undergoing further analysis for several reasons:

   a. To determine the ability to numerically distinguish between vegetation communities.

   b. To better determine Valley floor precipitation additional permanent stations for measuring precipitation will be established on the Valley floor. The locations of these stations will be determined in relationship to the presence of the two existing stations (Bishop and Independence) and the existing understanding of precipitation patterns.

2. Geographical Information System

   Establish a Geographical Information System (GIS) for the Owens Valley

   A GIS would assist in managing the hydro-ecological system of the Owens Valley by providing multiple map overlays of information pertaining to the Valley's natural resources. The data for the GIS are described in Section III.A.

B. Studies

1. Determine the statistical variability of all measurements and relationships presently used for monitoring. This will include:

   a. Point-frame measurement of leaf area (III.C)

   b. Psychrometer measurements (III.F)

   c. The Miller technique for estimating soil water content from soil water potential (III.F)

   d. Maximum effective rooting depths for common Owens Valley-floor perennials (III.G)

e. Absolute limiting water potential for several perennial species (III.G)

f. Depthwise decrementing for plant-available water (III.G)

g. Seasonal variability of average leaf angle for common Owens Valley-floor perennials (III.C)

2. Analysis of the techniques for estimating leaf area and transpiration

Analysis of the techniques for estimating leaf area and transpiration are ultimately used to project plant water requirements. These methods are currently being analyzed using data from the cooperative studies and collected during monitoring. The results of this analysis may be used to revise the techniques described in Sections III.C and III.D to achieve the greatest accuracy of the estimates.

3. Develop data and relationships that are presently estimated for untested species.

This would include:

a. Transpiration for several common perennial shrubs and forbs (III.C)

b. Average leaf angles for several common perennial species (III.C)

c. Absolute limiting water potentials for untested Owens Valley-floor perennials (III.G)

4. Statistical Ability for Determining Vegetation Change

Investigate the statistical ability for determining vegetation change on the Owens Valley floor using the existing transect record obtained during the inventory of dominant vegetation.

5. Remote Sensing (III.B)

a. Determine the patterns of climatic response and vegetation change using the existing satellite record beginning in 1974. This project should determine whether satellite imagery data is sufficient for tracking vegetation change.

b. Test and develop airborne systems to monitor the Owens Valley vegetation. This study will be tied closely with the implementation of the GIS.

6. Revegetation

Large-scale tests of revegetation and restoration should be attempted on Owens Valley floor lands. These tests should be made on a variety of soils in areas which have shown poor natural revegetation success. The goal of revegetation studies would be to establish perennial vegetation cover, though not necessarily to its previous composition. Restoration studies would attempt to restore an impacted area to its original vegetation cover and composition.

7. Rainfall Importance

Determination of the importance of rainfall in replenishing soil moisture. The study sites would be located in conjunction with the permanent precipitation stations noted above. Soil moisture measurements would follow established methodology

8. Type D Vegetation Monitoring Techniques

Riparian and marshland vegetation falls within the Type D management category. A study will be initiated to refine the present methodology and investigate alternative methods to improve monitoring of riparian and marshland vegetation.

9. Plant Responses

   The purpose of this study would be to gain an understanding of the demographics of Owens Valley plant species and how this vegetation responds to hydrologic management.

10. Erosion and Sediment Transport Along the Owens River

   Changes in riparian vegetation, sediment movement, and to old river oxbows and meanders from fluctuating flows in a natural river, such as the Owens River, are not well understood.

   In 1975, the U.S. Geological Survey, in cooperation with the Department of Fish and Game and LADWP, investigated the effects of long-term erosion and man's influence on river morphology of a segment of the Owens River below Pleasant Valley Reservoir.

   Los Angeles and Inyo County will re-examine and expand these investigations on the changes in the Owens River.

GLOSSARY

absolute limiting soil water potential: The soil water potential below which a plant is incapable of extracting additional water and which is achieved in the bulk volume of soil only with the presence of sufficient root density (see also limiting soil water potential and depthwise limiting soil water potential).

aquifer - A geologic formation, group of formations, or part of a formation that is water bearing and which transmits water in sufficient quantity to supply springs and pumping wells.

aquifer system - Two or more interconnected aquifers (e.g., a confined aquifer underlying an unconfined aquifer).

aquifer test - A field in situ study aimed at obtaining controlled aquifer system response data whereby a production well is pumped at several fractions of full capacity and/or at a constant rate, and water levels are measured at frequent intervals in the production well and nearby observation wells.

available soil water - That water in the soil that a plant can absorb. Per the techniques that have been adopted, this is the amount of water throughout the rooting zone calculated to be greater than the depthwise limiting water content in each of four soil slices.

average leaf angle - Leaves forming a plant canopy have complex alignments with no easily recognizable patter. Even so, when statistical and trigonometric techniques are applied on many individuals of the same species, a shared average angle of alignment is obtained. This average angle may then be used as a calibrated value to correct point-frame measurements to calculate leaf area index (LAI).

calibration - Developing and applying a mathematical relationship to interpret a measured value. Measurement of a parameter often requires the use of mathematical relationships to calculate a parameter from a reading that is obtained. Each psychrometer used for measuring soil water potential requires such calibration, and this calibration procedure shall be known as “psychrometer calibration.” Each monitored soil slice also requires calibration to apply the Miller curve technique, this shall be known as “Miller Method calibration.”

characteristic curve - A function relating the soil water potential to the soil water content. The Miller Method has been chosen as the means for calculating characteristic curves for interpreting the soil water at monitoring sites. Characteristic curves may use either weight or volumetric water content. The Miller Method utilizes weight water content to avoid systematic error of water content relative to soil water potential that may be induced by variable dry bulk density.

Day of Year - Abbreviated DOY, this refers to the calendar day of the year (from 1 to 365). Important plant responses, such as LAI and transpiration, can be modeled using DOY as the independent variable. A table is provided to permit calculating DOY from the calendar date.

TABLE FOR CALCULATING DOY FROM CALENDAR DATE

MONTH	JULIAN DAY
January	day of month + 0
February	day of month + 31
March	day of month + 59
April	day of month + 90
May	day of month + 120
June	day of month + 151
July	day of month + 182
August	day of month + 213
September	day of month + 244
October	day of month + 274
November	day of month + 305
December	day of month + 335

demographics - The study of populations and their distribution over time. Demographics is an important component of monitoring because the monitoring criteria were formulated to preserve the existing individual plants and does not address the cumulative effect of drought over time upon reproductive processes and recruitment.

depthwise limiting water potential - Due to problems of scale for measuring soil water potential and water content, the absolute limiting soil water potential for a plant is not achievable throughout the rooting zone. This occurs, in part, because root density decreases exponentially with depth. As the soil dries, the unsaturated hydraulic conductivity increases exponentially and water is essentially stranded in the soil volume that lies among rootlets. Thus, even though the water potential of the rhizosphere (zone immediately around each root) may approach the absolute limiting soil water potential, bulk measurements will show water content considerably in excess of that limit. This phenomenon induces a gradual depthwise increase in the measured limit for soil water extraction by roots. This increase in limiting water potential has been determined empirically under field conditions and has been termed “depthwise limiting water potential.”

dry bulk density - The soil dry bulk density, expressed as g/cm^3, is calculated by obtaining a volumetric soil sample from an undisturbed soil and dividing by its oven dry weight.

evapotranspiration - Abbreviated as ET, this term refers to water loss from natural areas as a combination of transpiration from plants and evaporation from the soil surface.

flowing well - A well penetrating a confined aquifer in which the water level rises above the ground surface.

hydrogeology - The study of groundwater, with particular emphasis given to its chemistry, mode of migration, and relation to the geologic environment.

hydrograph - A time series plot of water data.

hydrologic system - An assemblage of interrelated elements related to water flow, such as surface water systems, groundwater systems, and aqueduct systems.

intermountain slopes - Ungaged area between streams at the base of mountains.

leaf area index - Abbreviated as LAI and measured in units of m^2/m^2, this is a measure of leaf area per unit area of ground. Leaf area index is important because it is a driving function for transpiration and because it permits detailed numerical analysis of the vegetation growing on a site.

limiting soil water content - The soil water content corresponding to the limiting water potential. Limiting soil water contents are different for species with differing drought tolerances.

limiting soil water potential - The lower limit of osmotic adjustment which enables a plant to establish a gradient for flow into the root. This limiting water potential must be determined experimentally. Limiting water potentials will vary with species and - due to depthwise exponentially decreasing root density - with depth.

maximum effective depth of rooting - Abbreviated MED, is that depth where the functional density of roots approaches zero. This depth may be determined empirically by extracting cores under conditions when the water table is much deeper than the root zone. A line predicting root density per depth is then calculated using linear regression technique. The MED is the point where the line intersects the y axis (depth), thus predicting root density equivalent to zero.

Miller Method - Named for Reuben F. Miller, the researcher who suggested the method, this simple technique evaluates a logarithmic transformation of soil water potential - pF - as a linear function of weight water content for pF values in excess of 2.3. The point 2.3 represents the water retained after unimpeded gravity drainage. According to the family of Miller curves, any curve may be calculated using a modification of the quadratic formula given only one point of pF versus weight water content.

model - Simplification of reality - either conceptual or mathematical.

monitoring well - A well constructed for the purpose of observing or monitoring groundwater conditions.

mulch - Any nonliving plant tissue encountered during sampling.

pF - "Pressure force" is analogous to pH (the base 10 logarithm of the hydrogen ion concentration, using the absolute value of the base 10 exponent). pF may be calculated by first converting the water potential in MPa to pressure head expressed as cm of water, taking the absolute value and then the base 10 logarithm. This may be expressed as pF = log (10230*MPa). Note that MPa and cm of water head are both terms describing pressure, and that 1 MPa = 10 bars.

parcel (or vegetation parcel) - This is an area of land covered by vegetation of similar composition throughout and which is distinguishable from the surrounding vegetation cover.

phreatophyte - Used as a functional term to describe a plant that habitually receives a portion of its water supplied from the water table or overlying capillary fringe.

phreatophytic - Of, or pertaining to, a plant acquiring a portion of its water supply from groundwater.

piezometer - A test well for measuring the pressure head of groundwater. With a nonconfined system, the pressure head is equal to the free water table surface.

plant community - A recognizable association of plant species which grow together because of shared tolerances to climate and soil conditions.

point frame - A mobile structure used for sampling vegetation. Point frames generally consist of an upright frame with a cross piece through which pins are passed to sample the vegetation beneath. Pin contacts with leaves are judged only for pin points because the line of pin travel theoretically represents only one dimension. Since the sampling represents the pin-leaf contacts as a two-dimensional plane, calculation of LAI requires correction for the complex alignment of leaves.

recharge - Water that enters a groundwater basin - either from the surface or from the subsurface from adjacent basins.

recruitment - The process of replacement of aging and declining members of a plant community.

regression analysis - A statistical analysis of data that relates one variable (the dependent variable) to one or more independent variables.

remote sensing - Pertaining to acquiring or using data gathered by aircraft or satellite for studying processes on the Earth's surface. Examples of remote sensing data are air photos and satellite images.

retained water - Water that remains in a soil horizon following a drop of the water table and unimpeded drainage. Retained water is synonymous with field capacity and is roughly equivalent to a pF = 2.3.

root density - Is a measure of root length per unit volume of soil. Because root density does not follow a normal statistical distribution, before it can be treated using normal statistics, it must first be transformed by adding 1 and then taking the base 10 logarithm.

rhizosphere - The thin layer of soil lying immediately around all active roots of a plant which, due to processes involving hydrologic conductivity and dynamic diurnal fluctuations of root water potential, may have very different water potentials than the surrounding bulk soil.

runoff year - April-March

safe yield - The amount of water that can be withdrawn annually from a groundwater basin without producing an undesired result.

transect - A line which is located across vegetation to guide sampling. Since the placement of natural vegetation tends to be random, a linear feature, such as a transect, produces a random sample.

transpiration - The process of evaporative loss of water from plant leaves.

underflow - Lateral subsurface f low into and out of adjacent groundwater basins (e.g., Chalfant Valley and Round Valley).

volumetric water content - The soil water'content expressed in terms of the volume of water per volume of soil and may be in the form of either a decimal fraction or percent. Volumetric water content is calculated from weight water content by multiplying by the dry bulk density for that soil volume.

water year - October-September

weight water content - The soil water content expressed in terms of weight water per weight of soil. Weight water content may be expressed as either a decimal fraction or percent, and is determined gravimetrically after oven drying.

well - Any artificial excavation constructed by any method for the purpose of extracting water from - or injecting water into - the underground.

well field - A group of wells.

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