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Water Salvage Potentials in Utah, Volume I. Open Water Evaporation and Monolayer Suppression Potential

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WATER SALVAGE POTENTIALS IN UTAH

VOLUME I.

Open Water Evaporation and Monolayer Suppression Potential

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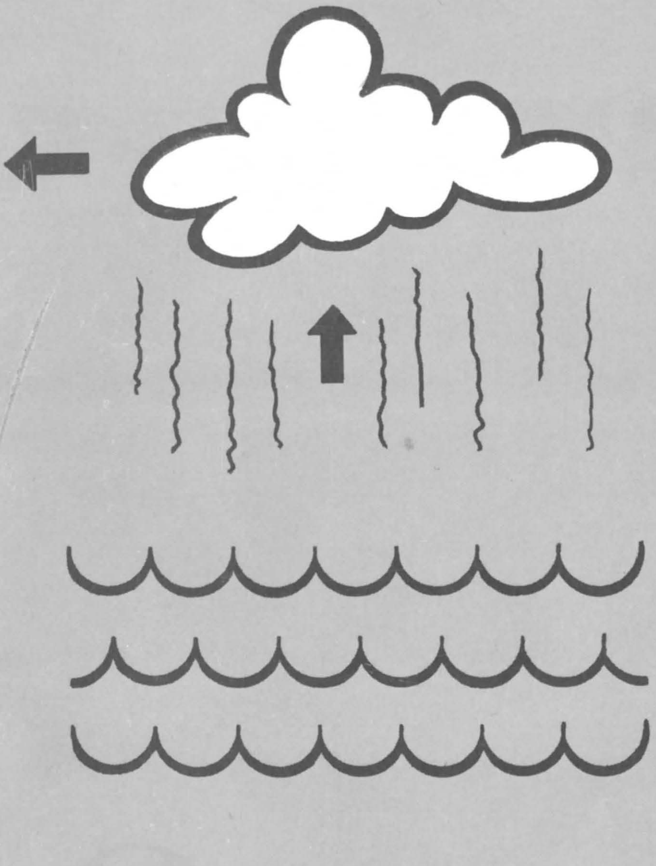

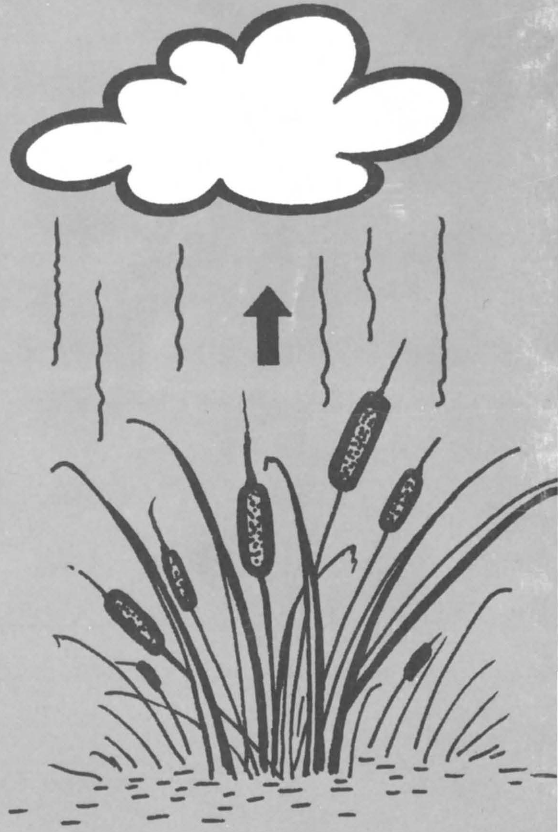

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Water Research Laboratory
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Water Salvage Potentials in Utah

Volume I

OPEN WATER EVAPORATION AND MONO-LAYER SUPPRESSION POTENTIAL

by

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July 1974

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ABSTRACT

An estimate of the potential in Utah for evaporation suppression by the monolayer film method is presented. The model estimates evaporation suppression as a function of wind speed, a four parameter exposure factor, and reservoir size. The estimated suppression factors vary from 0 to 30 percent and average 11 percent of the statewide total annual evaporation. Estimates of May to October evaporation and suppression potential are calculated for each of the 227 impoundments in the surface water inventory. A forthcoming report in this series will examine the potential for evaporation suppression by thermal destratification. This procedure, which is already being used for water quality improvement, appears to have greater potential than the monolayer concept for suppression on deep reservoirs.

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INTRODUCTION

Project Objective

This is the initial report of a project funded by the State of Utah for the purpose of examining water reuse and salvage potentials in Utah. The objective of the overall project is to quantify the potential for extending and augmenting Utah's water supplies by such possibilities as evaporation suppression and phreatophyte control.

Scope of This Report

Evaluation of both evaporation suppression and phreatophyte control requires as an initial step a detailed inventory of water which is now being consumed by evaporation from open water and by phreatophytes. A major portion of the project effort during the first year has therefore been used to develop statewide inventories of these consumptive uses. This report, however, will be limited to the open water evaporation inventory and suppression potential.

The primary method of evaporation suppression which has received research effort and funding in the past has been the use of a monolayer film. The evaporation suppression model developed and applied to the statewide evaporation inventory in this volume is limited to the monolayer suppression method (except for use of floating covers on very small impoundments).

Preliminary investigation of another method of evaporation suppression, that of thermal destratification, indicates that it may be more effective and considerably less expensive than the monolayer method. A suppression model for this method is being developed at the present time and will be published in a later report.

LITERATURE REVIEW

Scope

There is a rather large body of literature related both to methods of estimating evaporation and to evaporation suppression. In this section a selected portion of the evaporation suppression research will be described. Evaporation computation methods will be described as required within the body of the report. Readers interested in additional references in this area are referred to the following abstract bibliography:

> Office of Water Resources Research. 1973. Evaporation Suppression, a bibliography. U.S. Dept. of Interior, OWRR, Water Resources Scientific Information Center. WRSIC 73-216. Washington, D.C. 20240

Evaporation Suppression on Large Impoundments

The concept of reducing evaporation by applying a chemical film to the surface of a body of water is an old one. Benjamin Franklin experimented with oil films in 1765 and made a surprisingly accurate estimate of the film thickness which would be required (LaMer, 1962). Langmuir (1927) made major contributions during the 1920's by proving that certain acids and alcohols create films that are only one-oriented molecule thick (monolayer films) and that such films when compressed, conform to the same limiting area. Langmuir later determined that a true monolayer is more effective at suppressing evaporation than is a thicker oil film which consists of many layers of unoriented molecules. The chemical aspect of monolayer research, pioneered by Langmuir, Schafer and others, was continued during the 1950's by LaMer and Archer. These researchers developed accurate laboratory methods of measuring the effectiveness of suppression by various chemicals so that different materials could be evaluated. LaMer organized a symposium on evaporation suppression in 1960 at which many papers were presented. These were published as a monograph entitled, "Retardation of Evaporation by Monolayers: Transport Processes" (LaMer, 1962). This collection of papers is important because it includes not only theoretical and experimental laboratory results by chemists, but also the results of several applied field trials by engineers.

Many researchers have verified that two types of long chain alcohols, cetyl (hexadecanol) and stearyl (octadecanol) have desirable evaporation suppression characteristics. Octadecanol has superior resistance to evaporation (LaMer, 1962) but spreads much slower (Resnick and Cluff, 1963). A mixture of these two materials appears to be more effective than either material alone (LaMer, 1962).

An important consideration is the purity of the alcohol used. LaMer tested a sample of the hexadecanol/octadecanol mixture used on Lake Hefner and found it to be almost completely ineffective compared to the supposedly same mixture of pure materials tested in his laboratory. His conclusion was that many of the disappointing results experienced during field trials, which have been blamed on wind stripping, bacterial attrition, or other problems, were likely due to use of contaminated alcohol. LaMer recommends testing the purity in representative samples of every lot of commercial material prior to use in the field (LaMer, 1962).

One of the very difficult practical problems related to use of monolayer films is the method of dispensing the waxy chemical. Researchers have tried different solid forms such as pellets, powder, and flakes; heating to liquify it; and mixing with various solvents. The methods of dispensing have included broadcasting by hand, either automatic or manual spraying from rafts, boats, and airplanes, and allowing it to dissolve through a wire screen float. Various clogging, fire hazard, and other problems have been encountered but will not be discussed in detail here. Experience with various forms of material and methods of dispensing are described in the following literature :

1. Dispensing from aircraft in the solid and liquid form—Hansen and Skogerboe (1964), and Stringham and Hansen (1961).
2. Automatic dispensing as a liquid with various solvents—Resnick and Cluff (1963).
3. Dispensing as a water slurry—Roberts, in LaMer (1966), and Dressler in LaMer, (1966).

4. Dispensing dry powder from a boat—Vines, in LaMer (1962), and Fitzgerald and Vines (1963).

5. Automatic dispensing as a liquid from rafts—USBR (Sahuaro , 1961), and USBR (Cachuma, 1962).

Interest in evaporation suppression in the United States increased greatly in the mid-1950's when encouraging results of field trials performed in Australia were reported here. The Australian work by Mansfield (1953), Fitzgerald and Vines (1963), and others resulted in the following guidelines:

1. Savings up to 40 percent or more can be expected with winds up to ~ 5 mph.

2. Savings of 10-20 percent can be expected with winds up to ~ 10 mph, though occasionally savings may be somewhat less, depending upon prevailing conditions.

3. With winds persistently in excess of 15 mph, the savings approach zero.

Fitzgerald and Vines also suggest that ". . . if the wind exceeds 5 mph for a considerable time each day, then it would appear that on bodies of water of the order of one square mile in area, average savings of 10-20 percent are the most that can be expected."

Use of the Australian guidelines present several problems. In attempting to quantify a functional relation between wind and percent suppression one must reduce the general terms such as "up to 5 mph" or "exceeds 5 mph for a considerable time each day" to either average wind or some frequency distribution. What does up to 5 mph mean in terms of average wind, and what does considerable time each day mean in percent of time? These are problems which will be addressed in this report.

The optimistic results experienced in Australia have generally not been duplicated in the United States. The Bureau of Reclamation has sponsored several large scale field trials in this country with rather disappointing results. The first major suppression project was performed at Lake Hefner in Oklahoma (USBR,1958). This project involved several cooperating agencies and rather elaborate instrumentation by which evaporation and percent suppression were estimated. The results of three summer months of monolayer film maintenance were: 7 to 14 percent savings at various times with a 9 percent average. Winds during this period averaged 7 mph but the anemometer height was not reported.

A USBR project at Lake Sahuaro, Arizona, in 1960 produced savings of up to 22 percent but averaged 14 percent with winds averaging 5 mph (USBR, 1961). The film application period was delayed until October and only two fall months of suppression data were obtained.

The following year the USBR applied a monolayer film to Lake Cachuma, California, for two summer months (USBR, 1962). The results reported varied up to 22 percent savings but averaged only 8 percent. The winds averaged over 7 mph. The original savings during the film maintenance period was reduced by one-third due to increased evaporation after stopping the project. A stored energy effect causes an increase in surface water temperature due to the decreased evaporation. This stored energy increases evaporation after film applications have been stopped.

Several other researchers have made smaller scale tests in the U.S., some of which have reported better results than the USBR tests. For example, projects in Illinois reported savings of 22 and 43 percent on two small lakes (Roberts, in LaMer, 1962).

In response to a congressional committee directive, the USBR evaporation suppression program results were analyzed in 1970 by the Stanford Research Institute (Blackmer et al., 1970). Because of its important impact on continued research on this subject, the report's entire summary is quoted below:

> The Bureau of Reclamation has been engaged in evaporation reduction research since 1955. Work has centered on reservoir evaporation control using fatty alcohol monolayer films, with special emphasis on development of methods of chemical application. We believe that results of this program to date do not justify its continuation.
>
> In our opinion, the Bureau of Reclamation's research program has not yet proven that significant evaporation savings can be accomplished by the kinds of methods that they have investigated. Because of the inherent difficulty in measuring evaporation rates under field conditions, errors in estimation are large. When compared with the probable error of estimate, the estimated evaporation savings achieved by use of fatty alcohol films are not statistically significant. Furthermore, even if current best estimates of evaporation savings were correct, application of evaporation reduction techniques would be limited, because the cost of reducing evaporation generally would be greater than the value of water saved at the present level of water values in the 17 western states.
>
> There is some hope that chemicals not yet thoroughly tested such as ethoxylated alcohols, may prove superior to the unmodified alcohol. However, it is unlikely that improvements of sufficient magnitude will be made that will result in a practical, operational evaporation reduction program in the foreseeable future. In addition, there are a number of remaining problems, including the breaking of the monolayer film by moderate winds, that research will not solve easily.

Apparently as a result of this rather brief analysis, no further funds were approved for continuation of the USBR program of large-scale field trials with monolayer films. This apparently also had a spillover effect with other agencies and little interest has since been shown in continuing such research in the U.S. This SRI publication will be examined later in this report in some detail.

One of the SRI report authors, Joseph B. Franzini, had previously tested a monolayer film on a 40 acre reservoir in California and achieved a 20 percent suppression (Franzini, 1961). Estimated costs of water saved were $20-$35 per acre foot.

Most of the monolayer film literature consists of results of either laboratory or field trials on a particular reservoir. Little work has been done on developing models to extend existing empirical suppression results to other bodies of water. The results of aerial applications to several reservoirs by researchers at Utah State University (Hansen and Skogerboe, 1964) display many of the parameters graphically; but no way of estimating what percent suppression one may expect is given.

One attempt at such a suppression model is included in a doctoral dissertation by W. C. Hughes (1968). Hughes begins with the Australian guidelines previously given and modifies them by developing a correlation between suppression and surface area. The higher suppression results on U.S. field tests are assumed to compare with the higher Australian results and are therefore associated with a 5 mph average wind speed (thus ignoring the actual wind speed during these projects). The average results are similarly associated with the 10 mph wind speed and a percent suppression vs. wind speed function is thereby produced.

Literature on methods of suppressing evaporation on large reservoirs other than by monolayer films is almost nonexistent. Some authors mention such things as selecting reservoir sites to minimize the surface area/capacity ratio, and diking to eliminate large shallow areas which lose more than they contribute to storage. The application of such methods is obviously limited and the monolayer method concept appears to be the only one which has received serious consideration by researchers.

Environmental Effects of Monolayer Film

A summary of reports on toxity of long-chain alcohols was published by Israelsen (1962). It included several statements from Public Health Service researchers that no hazard to public health should result from the intended use. These alcohols are described as normal metabolites of commonly ingested food stuffs.

A study made at Colorado State University for the Bureau of Reclamation was addressed to biological effects of hexadeconal (Hayes, 1959). This study revealed no change in mineral quality of the water, a small decrease in oxygen diffusion at the air-water interface, and temperature increases at the water surface of 2.6 to 3.8°F. Also, the surface tension was decreased by 55 percent. The conclusion was that most biological effects are small ("well within the range of natural variation") except for the surface tension effect. Emerging insects which depend on surface tension for support are likely to be adversely affected.

Other researchers have observed significant increases in bacteria population due to the presence of long chain alcohols. The most serious problem in this regard appears to be the cost of replacing the alcohol ingested by the bacteria (and by fish). When the film application is stopped, a rapid loss in bacteria population occurs and approaches the pretreatment level within three weeks (U.S. Dept. of Interior, 1959).

Evaporation Suppression on Small Impoundments

Because of the relatively constant depth of water evaporated, losses increase in terms of percent of water stored as the size (depth) of reservoir decreases. On small farm ponds often more water is lost by evaporation than is used. For this reason, much research effort has been and is still being expended on evaporation suppression on small impoundments (less than 10 or 20 acres of surface area).

Initially much work was done with monolayer film concepts on small ponds. P. L. Silveston, for example, estimated 10 to 25 percent suppression could be achieved at costs of $21 to $94 per acre-foot depending on wind, dust, and wage rates (Silveston, 1965).

Most researchers now, however, agree that because of the rapid stripping action of wind on small reaches, chemical films are not feasible on small ponds. The majority of research work being done now, as well as the predominant amount of working field application is focused on more permanent floating covers. Such covers cost much more than a chemical film initially, but often last for several years, not requiring daily replacement. The high initial cost is also balanced by higher suppression efficiency (commonly 65 to 95 percent). Most of this work has been done in the southwestern U.S., and particularly at the ARS Water Conservation Laboratory in Phoenix, Arizona. Intensive evaporation suppression is a necessary final step in most water harvesting concepts. A symposium on the subject was held in Phoenix in May 1974 which attracted participants from several countries including Australia. The proceedings of this symposium include several papers giving costs, percent suppression, and maintenance problems encountered with various types of floating covers (ARS, 1974).

A summary of research at the Phoenix laboratory on various pond covers is given by Cooley and Fink (1974). Methods of suppression investigated include:

1. Changing reflecting properties of water by dyes.
2. Floating covers such as perlit ore, Polystyrene rafts and beads, wax blocks, and butyl rubber.
3. Shading the surface with plastic mesh.
4. Installing wind barriers.

Efficiencies varied from 6 to 95 percent with the more effective methods costing $1.00 or less per 1,000 gallons saved.

Prospects for Future

Despite the rather discouraging results of the USBR projects in this country, and the elimination of further research financing caused by the SRI report, research on monolayer films is continuing on a small scale in the U.S. and in other countries such as Canada (Lapp, 1968), Australia (Macritchie, 1969), and Israel (Reiser, 1969).

An interesting idea has been presented by William D. Garrett (1971). He suggests that under even moderate wind conditions the common n-alkanol monolayers rapidly lose their ability to act as a vapor barrier due to the reduction of film pressure. However, the striking ability of the film to dampen waves exists at very low film pressures and this may be even more important than the vapor barrier effect in regard to reducing evaporation under windy conditions. He indicates that other types of alcohol such as more rapidly spreading oleyl alcohol dampen waves both in the capillary range and the gravity breaking waves (wind speeds to 20 mph); and that such dampening has a significant effect on the vapor transport mechanism which causes extremely high evaporation under windy conditions. This is a different concept of evaporation suppression with a chemical film which should be investigated.

Another promising approach to evaporation suppression is that of lowering the water surface temperature by thermal destratification. This concept has not been evaluated at all in the literature. The potential of this approach will be investigated during the second year of this project.

EVAPORATION FROM OPEN WATER IN UTAH

The necessary first step in estimating how much water can be salvaged by evaporation suppression is to determine a reasonably accurate estimate of normal evaporation. This is so because evaporation suppression is normally expressed as a percent of the natural rate. Any error in the natural evaporation estimate therefore becomes a component of error in the salvage estimate. Because the rate of evaporation varies with wind, temperature, and relative humidity, which in turn vary with climatic cycles, a long term average evaporation estimate is necessary to predict expected values of salvageable water. The necessary information for estimating normal amounts of evaporation from water surfaces on a statewide basis fall logically into two categories: (1) determination of average surface area for each body of water, and (2) estimation of the average depth of water evaporated from each body of water.

Surface Storage Inventory

Data sources and procedure

Existing information on reservoirs and lakes was gathered from various sources. Several different agencies have developed surface storage data which were helpful, but none of which were adequate by themselves. Principal data sources were:

(1) State Engineers Office: By statutory requirement any construction of a storage reservoir in Utah requires approval by the State Engineer. Such approval requires submission of reservoir plans. This office was therefore a primary source of data such as name, location, maximum surface area, and capacity of man-made impoundments down to as small as 5-acres of surface area. The State Engineer records, however, do not include data on most large reservoirs constructed by federal agencies such as the Bureau of Reclamation.

(2) Interagency Framework Studies: The Pacific Southwest Inter-Agency Committee Reports on the Upper Colorado (1971) and the Great Basin Regions (1971) both include reservoir inventories consisting of maximum surface areas and capacities.

(3) Bureau of Reclamation: Data on USBR impoundments which were recently constructed (or are under construction) or for other reasons were missing from other inventories, were obtained from the USBR Regional Office in Salt Lake City. This information included area-capacity curves and USBR evaporation estimates on Flaming Gorge and Lake Powell.

(4) Other Regional Inventories: Thomas and Harbeck (1956) inventoried man-made reservoirs with over 5000-acre-feet capacity. Myers (1962) extended this inventory to smaller and natural lakes by a statistical sampling procedure in 17 western states. This inventory aggregates data by river basin and state rather than listing individual reservoirs. This publication also develops a statistical relationship between maximum surface area and effective area (in terms of evaporation). However, the data for this function included only two Utah reservoirs. An analysis of 18 Utah reservoirs for which several years of storage records are available (from USGS surface water records) indicated a very different size/effective area relationship. This analysis will be described in a later section.

(5) Other state inventories: The Utah State Division of Health has assembled an inventory of both man-made and natural impoundment surface areas. However, comparison with various other sources indicated that this list includes substantial errors in many reservoirs. The Utah State Division of Fish and Game has inventoried open water in wetland areas (Nelson, 1966; and Regenthal and Jensen, forthcoming). These were helpful in separating natural open water areas from phreatophyte areas in wetland environments.

The various existing inventories collectively provided a relatively complete, although frequently conflicting list of man-made impoundments. Considerable effort, including a site visit to many impoundments was required to cross check for completeness and accuracy of these data.

Size data for natural lakes, ponds, and wetlands were not as readily available and much of this portion of the inventory was planimetered from USGS topographic maps.

The open water inventory was classified as follows:

I. Salt Water: (Great Salt Lake only)

II. Fresh Water:

Natural Lakes	over 1000 acres 100 to 1000 acres under 100 acres
Unmanaged Wetland	(any size)
Man-made Lakes (or natural but regulated by man)	over 1000 acres 100 to 1000 acres under 100 acres
Managed Wetlands (any size)	Federal State Private

In addition to this classification, summaries were made of each major hydrologic basin in the state. Each body of water was assigned a number by which it could be located (Figure 1). The reservoir name, number, and size data are listed in Appendix B. In the case of unmanaged wetlands in a particular area, a single number was assigned to several unnamed bodies of water.

The final step in the preparation of the reservoir size and location inventory was a visual inspection of the major reservoirs throughout the state. The on-site evaluations provided additional information and also served as a verification of the published records. Reservoir site characteristics were noted for determination of the site factor. This in an index used to compute suppression efficiency which will be described later. Climatological parameters were recorded at the same time as an aid for estimating the exposure index, which is defined in the appendix on evaporation computation.

Effective area

One of the difficult aspects of a statewide evaporation estimate is determining the proper fraction of the maximum surface area which will best represent the "effective area." This is defined as the surface area by which the seasonal or annual evaporation depth can be multiplied to produce the best estimate of volume evaporated. This is not simply the average physical seasonal or annual surface area, because the periods of high evaporation need to be weighted differently than the area for colder months in order to approximate the evaporation volume. In order to estimate effective areas for Utah, 18 reservoirs for which historic storage data are available were analyzed in the following manner: the end of month capacities for each reservoir were averaged for all years of record. These figures were converted to surface areas by using the portion of the elevation/capacity given in the water supply records and extrapolating on log paper as required. Using the average monthly surface areas, the average May to October volume of evaporation was computed for a sample of eight sizes and types of reservoirs by using a monthly evaporation depth model as follows:

Month	Percent of May-Oct. Evap.
May	13.3
June	20
July	21.4
Aug.	18.7
Sept.	16
Oct.	10.6
	100

This temporal evaporation distribution is based upon monthly amounts developed by the Soil Conservation Service (SCS, 1969) for central Utah. The total seasonal volume of evaporation for each reservoir was then used to determine a single surface area which would have produced the same volume of loss (the effective area). The hope was that the average area occurring at a particular time of the year would approximate this effective area. Analysis of the data showed that the area at the end of July is surprisingly close to this figure for all reservoirs as shown in Table 1 (average error was 2 percent). The end of July was therefore used for all other reservoirs for which these data were available.

The ratio of effective area (end of July) to maximum area is given in Table 2 for all reservoirs for which data were available. No apparent significant relationship exists between this ratio and size of reservoir in terms of either surface area or volume. The ratios for Utah reservoirs are substantially different than those developed by Myers (1962). Myers (using only two Utah data points) suggested, for example, a ratio of two-thirds for reservoirs larger than 1000 acres and one-third for those smaller than 400 acres. In order to estimate the effective area for Utah water for which no storage data were available, the following effective/maximum ratios were used:

Small or shallow impoundments	.65
Deep impoundments or those known to remain essentially full	.90
All others (except where site visit or personal knowledge indicated otherwise)	.80

Utah Wind Analysis

Any analysis of potential for evaporation suppression will determine very quickly that wind is

Table 1. **Comparison of end of July area to effective area from evaporation model.**

No.	1 Reservoir	2 Max. Surf. Area (ac)	3 End of July Area (ac)	4 Effective Area (ac)	5 Ratio (4/3)
25	Willard Bay	9,950	9,900	9,894	.9994
33	Bear Lake	70,500	70,000	69,787	.997
40	Hyrum Dam	480	434	444	1.023
53	East Canyon	684	552	545	.987
54	Echo	1,470	1,254	1,224	.976
109	Flaming Gorge	41,800	31,300	30,112	.962
141	Scofield	2,810	2,520	2,538	1.007
176	Piute	2,598	1,420	1,491	1.050

Table 2. **Ratio of effective (end of July) to maximum surface area.**

No.	Reservoir	Effective Area	Maximum Area	Ratio
25	Willard Bay	9,900	9,950	.995
33	Bear Lake	70,000	70,500	.993
40	Hyrum	434	480	.904
45	Pineview	2,626	2,870	.915
46	Lost Creek	330	365	.904
53	East Canyon	552	684	.807
54	Echo	1,254	1,470	.853
64	Rockport	991	1,080	.918
97	Moon Lake	702	1,150	.610
101	Utah Lake	80,877	95,900	.843
109	Flaming Gorge	31,300	41,800	.749
129	Sevier Bridge	2,572	10,905	.236
141	Scofield	2,520	2,810	.897
176	Piute	1,420	2,598	.547
177	Otter Creek	1,831	2,768	.661
225	Lake Powell	114,000	162,700	.701
230	Joe's Valley	867	1,170	.741
			Ave. Ratio	.781

the dominant parameter. This is true in regard to any method which requires a vapor barrier over the surface. Effectiveness of a chemical film is obviously related inversely to wind speed and frequency. Floating covers on small ponds often work well until high winds displace or destroy them. For this reason, a substantial effort has been devoted to analyzing wind speeds and frequency distributions in Utah.

Pan data

Unfortunately, historic wind data are not available at most reservoir sites. Most of the data which are typically used are from the nearest Class A pan station. The evaporation pan anemometers are located 2 feet above the ground surface. These data have several problems in regard to use for wind estimates at reservoir sites:

1. The pans are usually located at climatalogical stations, not at reservoir sites. Making inferences about reservoir wind from a pan anemometer located even a few miles away can be very inaccurate because of differences in site exposure conditions. This is particularly true in mountainous locations.

2. Pan data consist of total wind movement in miles per day or per month. Such data give average wind speed, but reveal little about instantaneous speeds or daily peaks. They can, however, be used as indices of probability of certain wind speed thresholds which will be discussed later.

3. Pan anemometers almost always have significantly different exposure conditions than an instrument located near to or on a reservoir. In fact, many of the pan data in Utah show a gradual decrease in average wind speed from May to October. Most data from higher anemometers such as at airports do not show this same seasonal decrease (although some sites do indicate higher spring winds). The difference is clearly due to the growth stage of surrounding vegetation. The surface roughness changes as surrounding plants mature. In fact, the Utah State Climatologist indicates that each time a crop of hay is cut, it has a significant effect on wind data at certain anemometers which are surrounded by alfalfa fields. Since a reservoir surface is much smoother than a typical land surface (except during high wave conditions) a serious transference problem exists. A correlation between airport and pan anemometers developed later in this report indicates that pan wind speeds are typically two-thirds of 2-foot winds which are derived from higher anemometers and reduced by the power law.

Regardless of the problems associated with pan wind data, they are by far the most extensive wind data available. This research has established the fact that they have real value in estimating reservoir winds provided that the extrapolation is done by a climatologist armed with knowledge of exposure conditions at both the pan and the reservoir. A substantial amount of effort during the initial year of this project was devoted to determining exposure conditions at the major reservoirs in Utah. The exposure factors are essential, not only for estimating evaporation, but also for estimating evaporation suppression (suitability for film maintenance).

Pan wind data do have the important advantage that they are correlated in time and location with pan evaporation data (which are used to estimate reservoir evaporation). Also, a few Utah pan stations are located on reservoir shorelines so that most of the problems described herein do not apply.

A summary of pan wind data (as well as related evaporation and maximum and minimum water temperature) from 34 National Weather Service stations has been published by the Utah State Climatologist (Richardson, undated pamphlet) and the standard deviations for these data were computed during this project. From these raw data Richardson has also computed normalized 1941-70 pan winds and evaporation for these stations on a monthly (May to October) basis.

Airport data

The other major source of wind data in Utah is airport anemometers. This is a different form of data and has some advantages over pan data. One of the important factors in regard to suitability of a reservoir for use of a monolayer film is the frequency of winds of sufficient velocity to remove the film. Airport data are recorded at various intervals depending on the type of instrumentation and the availability of personnel. Most airports record wind speed at 1-hour intervals, but others use 3 or 6 hour intervals. The 1-hour interval is considered about optimum for evaporation suppression analysis. Gusts of short duration aren't significant in terms of stripping a film (except on extremely small ponds where the film method is not practical anyway). Intervals of 6 hours produce data which are not as accurate in representing frequency distribution of particular wind speeds during a 24-hour period due to the dampening or smoothing affect of missed peaks if, however, enough years of record are used to produce the distribution, the accuracy is improved.

Airport data suffer from the disadvantage that the anemometers are located higher above the surfaces than is desirable for evaporation analysis. The 11 airport stations used in this project had anemometers varying in height from 15 to 60 feet. Due to the viscosity of the air and the dampening effect of the ground or water surface, wind velocity, in general, increases with distance from the earth's surface. The most widely accepted functional relation between elevation and wind speed is the "power law":

$$\frac{U_1}{U_2} = \left(\frac{Z_1}{Z_2}\right)^c$$

U and Z represent wind speed and distance from ground surface respectively at elevations one and two; The exponent c has been found to vary both with surface roughness and wind velocity. Gutierrez (1970) found that for average wind speeds across a grassy surface, c was 0.296. In this report a value of c = 0.3 was used. Figure 2 is a graphical representation of the resulting function.

One of the surprising aspects of the literature search was the difficulty of determining the anemometer heights used on various evaporation measurement and evaporation suppression research projects. The published literature gives many data on average wind speeds and some on wind speed frequency distributions but quite frequently no anemometer elevation is given. Occasionally, photographs of the instruments are given from which one can estimate the approximate height. This frequent omission is unfortunate because suppression effectiveness data cannot be compared until average wind speeds have been reduced to a common height basis by the power law. The power law defines the following vertical gradient for wind speed.

Table 3. Wind speed elevation relationship.

Wind at anemometer (U_2) of 10 mph at the following heights	Wind at 2 meters (U_1) = KU_2
2 feet	14.3
2 meters	10
10 feet	8.8
15 feet	7.8
20 feet	7.15
25 feet	6.7
30 feet	6.3
40 feet	5.8

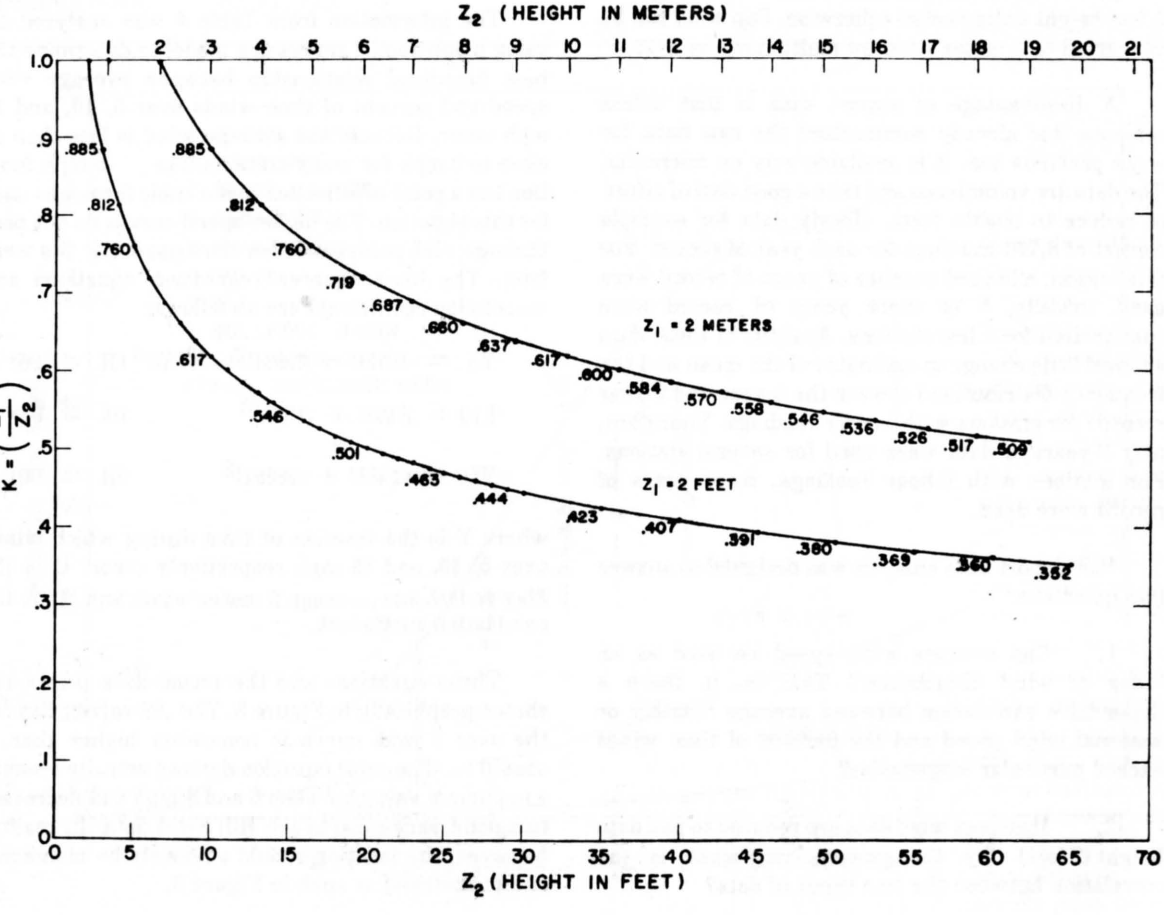

Figure 2. Vertical Wind Speed Profile.

As indicated in Table 3, at elevations near the ground surface a significant gradient occurs. The 2-meter height was selected for this project as the common height at which wind speeds are to be compared. As Table 1 shows, if an anemometer is at 40 feet but is thought to be at 30 feet, the 10 foot error would produce a relatively minor 8 percent error in the 2-meter estimate. On the other hand, if an anemometer at 15 feet is assumed to be at 2 meters, the 8.5 foot error in elevation produces a 28 percent error in wind speed (assuming the power law is accurate).

Another factor which can introduce error in comparing pan and airport data is that pan winds are usually in miles per hour (mph) while airport winds are recorded in nautical miles per hour (knots). The relationship is as follows:

mph = 1.15 knots

Some of the literature speaks of wind speed based on airport data without specifying which dimensions are used. In this report all wind data will be in mph at 2-meter height unless noted otherwise. The exception to this are pan data which will be mph at 2-foot height unless noted otherwise. Pan wind can be converted to 2-meter wind by multiplying by 1.42.

A disadvantage of airport data is that unless someone has already summarized the raw data for some previous use, it is available only on microfilm. The data are voluminous and take a good deal of effort to reduce to usable form. Hourly data for example consist of 8,760 readings for each year of record. For this reason, a limited number of years of record were used. Initially, 5 or more years of record were summarized for a few stations. Analysis of these data showed little change in estimates of the mean and the frequency distribution between the 5-year and 3-year records for stations with hourly readings. Therefore, only 3 years of data were used for several stations. For stations with 6-hour readings, more years of record were used.

The airport data analysis was designed to answer two questions:

1. Can average wind speed be used as an index of wind distribution? That is, is there a dependable correlation between average monthly or seasonal wind speed and the percent of time winds exceed particular magnitudes?

2. If airport wind data are reduced to pan data height (2 feet) by the power law, what is the correlation between the two types of data?

To address these problems data from ten airports in Utah were summarized. The statistics which were estimated were:

1. Average wind speed at 2 meters.
2. Percent of time wind exceeds 5 mph.
3. Percent of time wind exceeds 10 mph.
4. Percent of time wind exceeds 15 mph.

These exceedance magnitudes were selected from a literature review based upon identifying a range of wind speeds which are indicative of particular threshold effects on a monolayer film.

Wind is normally considered to be extremely site specific. That assumption was not refuted by this study; however, a rather good correlation was found between average wind and frequency of certain wind speeds, regardless of the type of site. Table 4 summarizes the May to October airport wind data. Monthly data for these stations are given in Appendix C.

The information from Table 4 was analyzed by using a polynomial regression model to determine the best functional relationship between average wind speed and percent of time winds over 5, 10, and 15, mph occur. Because the average wind is less than or close to 5 mph for many stations, the 5 mph function has a point of inflection and a cubic form was used for this equation. The higher speed curves do not pass through such points and therefore quadratic fits were best. The least squares regression equations and correlation coefficients are as follows:

$$Y5 = -10.1U + 6.68U^2 - .583U^3 \quad (R = .96)$$

$$Y10 = .843U + .182U^2 \quad (R = .84)$$

$$Y15 = -.148U + .0869U^2 \quad (R = .66)$$

where Y is the fraction of time during which winds over 5, 10, and 15 mph respectively occur, U is the May to October average 2 meter wind, and R is the correlation coefficient.

These equations and the actual data points are shown graphically in Figure 3. The .96 correlation for the over 5 mph curve is somewhat higher than it should be. The cubic equation derived actually reaches a maximum value between 6 and 8 mph and decreases to a point very close to the Hill Field data. In reality, however, the function should obviously be monotonic and is sketched as such in Figure 3.

Table 4. May-October wind speed and frequency distribution.

Airport location	Years analyzed	Data frequency	Avg. 2 meter wind mph	% of time wind exceeds these speeds at 2 meter weight 5 mph	10 mph	15 mph	Height of Instrument
Hanksville	63, 64, 65	1 hr.	4.62	39.9	13.7	3.35	25'
Bryce Canyon	67, 68, 69	1 hr.	4.59	41.7	5.2	0.1	38'
Cedar City	67, 68, 69 70, 71	1 hr.	4.6	41.9	8.76	1.0	42'
Hill AFB	41 to 65	1 hr.	7.8	51.7	16.7	4.0	15'
Delta	39, 40, 41	From existing wind rose	5.1	46.0	6.5	0.1	30±
Salt Lake City Airport	50 to 60, + 70, 71, 72	1 hr.	5.75	52.1	10.1	1.5	20',33',58'
Green River	61 to 71	6 hr.	3.2	16.7	3.35	0.5	26'
Wendover	42 to 65	1 hr.	3.9	21.3	3.1	0.5	22,31,60
Ely	70, 71, 72	1 hr.	5.35	53	6.3	0.5	47'
Bullfrog Basin	70, 71, 72, 73	6 hr.	5.67	41	14.1	4.3	22'

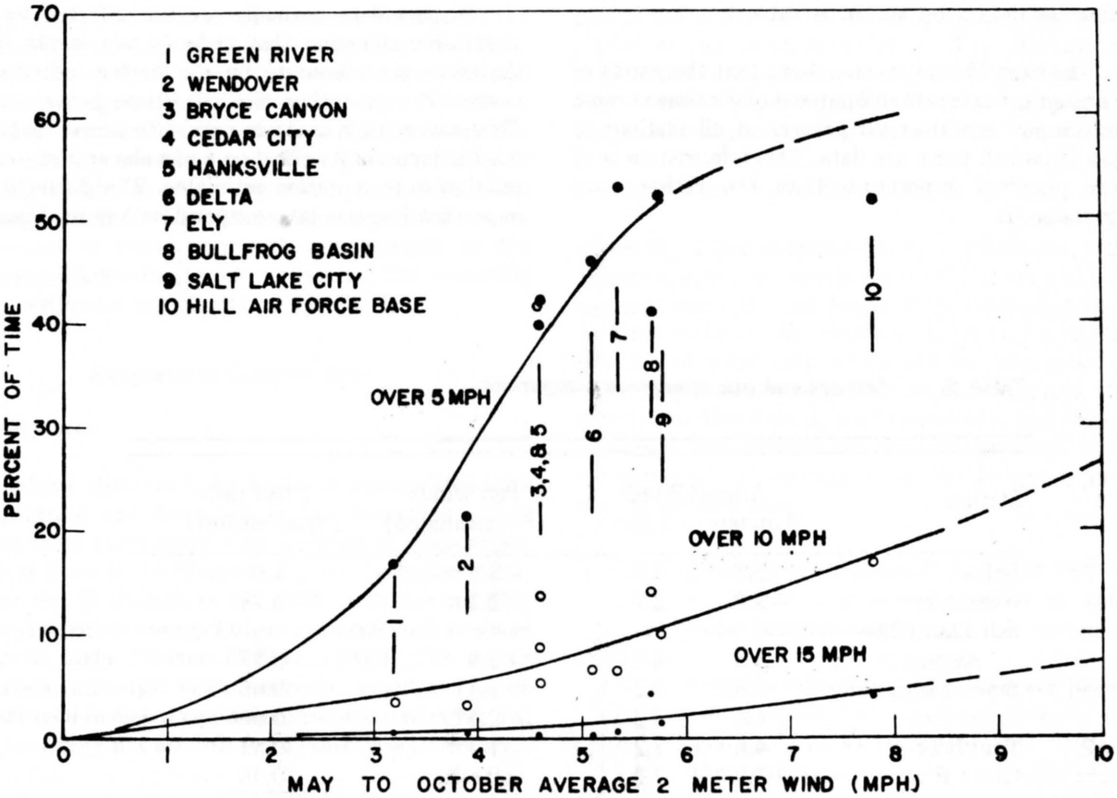

Figure 3. Seasonal wind frequency distribution.

The over 10 mph curve is the more important of the three curves because sustained winds at or above this speed result in a rapid decrease in evaporation suppression. It is interesting that the correlation for this function could have been increased from .84 to over .95 by deleting the Hanksville and Bullfrog data. These two stations are within 50 miles of each other and apparently experience quite different wind distributions than the other eight stations. Additional data and analysis of the site conditions may reveal a means of defining more than one function for each speed threshold depending on site factors. However, in this initial analysis a correlation coefficient of .84 was considered adequate and the function appears to be useful in its present form.

Salt Lake City data were originally based upon a published 10-year summary. The anemometer location however, was changed twice during the 10-year period. This made it difficult to select a reliable factor by which to reduce the data to a 2-meter basis. For this reason three additional years of data were reduced from microfilm. Both summaries are shown in Appendix C as "Salt Lake City Original" and "Salt Lake City New." The two distributions are very different and it would be desirable to verify the distribution at the present site by using additional years of record. However, for this report these two summaries were combined (with equal weight) to create the data point shown in Table 4.

The over 15 mph curve shows that the winds of this range occur less than 2 percent of the time at most stations and less than 4.3 percent at all stations in Utah for which there are data. This information is of more practical importance than the rather poor regression fit.

The correlation coefficient for at least the over 5 and 10 mph curves appears to answer in the affirmative the question posed previously. Average wind speed appears to be a good index of wind speed distribution.

The results portrayed in Figure 3 were used to develop the evaporation suppression model shown in Figure 4. The scales at the top of that figure are based upon the best fit lines shown in Figure 3.

The other objective of the Utah wind data analysis was to compare pan data to airport data and examine the implications of the inherent shielding differences. This is a difficult task because, ideally, what is needed is pan and higher elevation data at approximately the same point. There are only two locations in Utah where both types of data are available — Salt Lake City Airport and Green River. The Utah State Climatologist, however, had previously estimated pan winds at several of the locations at which airport data are available (Richardson, unpublished report). This estimate was based upon knowledge of exposure conditions at these sites and a correlation with adjacent measured pan winds. A comparison of airport and pan winds, both measured and estimated, were thus possible for seven stations in Utah. This comparison is shown in Table 5.

Airport data normally are not affected by the vegetative shielding that reduces pan winds. It is therefore considered to be the better indicator of reservoir wind (other site conditions being equal). This statement is made in regard to actual reservoir wind in terms of its effect on a monolayer film—not in relation to evaporation estimates. The distinction is important because lake evaporation has traditionally

Table 5. Airport and pan wind data comparison.

Station	Airport Winds 2 meters	Airport Winds 2 feet	Pan Winds (* = estimated)	2 feet ratio (pan/airport)
Delta	5.1	3.5	3.5*	1.0
Wendover	3.9	2.7	2.1	0.78
Salt Lake City Airport	5.8	4.4	2.9	0.75
Bryce Canyon	4.6	3.2	2.1*	0.66
Cedar City	4.6	3.2	2.1*	0.66
Hanksville	4.6	3.2	1.7*	0.53
Green River	3.2	2.2	0.84	0.38
			Average	0.68

been computed as pan evaporation corrected by a pan coefficient. When such estimates are made for reservoirs at which there are no pan data, the accepted procedure is to estimate the wind and temperature parameters necessary to compute pan evaporation from an equation of the form discussed in the next section and then to apply the accepted pan coefficient. In this case, the wind estimated should be the pan wind, not the corrected or airport type wind.

Having made this distinction, it is proposed that monolayer stripping wind estimates (Model A) be based upon 2-meter elevation winds; and that where pan type winds are the basis for such winds, that they be adjusted by the average ratio from Table 3 as follows:

$$U_{2m} = U_p \left(\frac{1}{.68 \times .702}\right) = (2.1)\, U_p$$

where U_{2m} is the 2-meter reservoir site wind hereinafter referred to as reservoir wind; U_p is the 2-foot pan wind; and .68 and .702 are respectively the shielding and elevation correction factors.

Reservoir wind estimates

Using the 30-year normal winds at Utah pan stations and several other related parameters as a data base, average May to October reservoir winds were estimated for each surface storage location in the state. These wind estimates were then used for calculating evaporation (2-foot winds) and potential percent suppression (2-meter winds) of May to October evaporation. A substantial effort went into this estimate, including a visit to each reservoir site during which exposure conditions were noted and photographed. Details of the exposure parameters are discussed in connection with development of the exposure index in the next chapter. The reservoir wind estimates are given in Appendix D.

Evaporation Computations

Fresh water

Many different methods of estimating lake evaporation are described in the literature. They range from using maps with iso-lines of evaporation such as those in the Weather Bureau Technical Publication No. 37 (Kohler et al., 1959) to rather complex water budget or energy budget methods such as those used at Lake Hefner (USBR, 1959). The latter methods, although more accurate, require a large investment in instrumentation and data gathering and are obviously not feasible for a statewide inventory.

The previously published evaporation maps which included the Utah area were not considered adequate for the objectives of this study. Kohler's evaporation map of the 17 Western States was based upon 10 years of pan data ending in 1955. Additional evaporation data are now available in Utah and the Utah State Climatologist (Richardson, 1971) has recently summarized and published pan evaporation, wind, and maximum and minimum temperature data from 34 Class A evaporation pan stations in Utah. From these data Richardson has also determined normalized evaporation and pan wind estimates for these stations for the 1941 to 1970 period.

One method for computing pan evaporation was developed at USU by Jerald E. Christiansen (1966). It is based upon regression equations from historic data for the various climatic parameters considered. The method requires estimation of mean temperature, wind, relative humidity, sunshine percentage. These are essentially the same parameters (plus sunshine percentage) as are required for the Richardson method used in this project which will be described next. The Christiansen methodology may have provided comparable accuracy to the method used, however, the Richardson method had already been applied to 139 stations in Utah. This provided a substantial data base as a starting point for computing evaporation at each reservoir in Utah. Also the Richardson method was more adaptable to the type of inventory developed in this project. It required site exposure factor data which related to and provided part of the site factor for the evaporation suppression model to be described later. The Richardson evaporation computation method is described in a brief separate paper included herein as Appendix A. Richardson began with the classic Dalton equation:

$$E_p = (e_s - e_a)\ a\ f(u)$$

where E_p is pan evaporation, e_s is saturation vapor pressure, e_a is the vapor pressure of the air, and a is a constant and u is wind speed. Richardson found that for Utah stations, the "constant" is actually a variable function of wind only which can be eliminated by classifying each site as to location exposure and wind conditions. Also since e_a is a function of e_s and relative humidity, the Richardson method requires either measurement or estimation of the following parameters for each site:

1. Average vapor pressure at water surface, e_s (which is a known function of mean water temperature).

2. Relative humidity. These data are usually not available but can be estimated adequately from elevation and knowledge of site conditions.

3. Mean wind speed. These data are not available at most sites but can be estimated

by examining wind data from nearby sites combined with a knowledge of site conditions.

4. Classification of the site into one of three categories:

    a. Flat valley sites with pan wind less than 60 miles per day.

    b. Flat valley sites with pan winds of 60 to 90 miles per day.

    c. All canyon sites and valley sites with pan winds over 90 miles per day.

Richardson had previously used the regression equation resulting from the 34 pan data stations to compute evaporation at 105 other climatological stations in Utah (stations at which temperature but not evaporation data were available). From these data points a pan evaporation iso-line map of Utah was constructed (Figure 4). This represents Utah pan evaporation with much better accuracy than previous iso-maps. However, in mountainous topography (where most Utah reservoirs are located) even this improved map could produce serious errors. The primary difficulty is in extrapolating the value of the wind parameter. Wind speed is highly site specific. It can be estimated adequately by a climatologist who has a knowledge of the up-slope basin shape, slope, size, elevation, and vegetation, but cannot be simply interpolated between adjacent sites which may possess different exposures. For this reason, evaporation was calculated individually for each body of water included in the reservoir inventory by using the Richardson equations. To illustrate the size of error one can expect from using Figure 4 to estimate evaporation at Utah reservoirs, the following comparison was made:

1. The pan evaporation at each man-made reservoir which is over 200 acres was estimated from the iso-line map (Figure 4).

2. The ratio between this evaporation and that from the Richardson equation was determined.

3. The ratios were categorized as those at reservoirs over or under 7000 feet in elevation.

The analysis showed that Figure 4 gives good results for reservoirs under 7000 feet (average ratio = 0.999 with a standard deviation of .148). For higher elevation reservoirs, however, Figure 4 overestimated evaporation by an average of 57 percent (ratio = 1.57 with standard deviation of 0.45). This agreement at low elevations and large error at high elevations simply reflects the sparsity of climatological stations at high elevations. A much better lake evaporation contour map (Figure 9) is developed later in this report based upon the evaporation calculation for each reservoir included in the inventory.

In order to develop data necessary for estimating the required evaporation parameters, all major reservoirs (those over 1,000 acres surface area) in the state were visited. In addition, all smaller reservoirs which were located close to the route required for major ones were also visited. Colored photographs of each site were taken, wind direction, data, and time were recorded, and other exposure data for use in the suppression model were noted. By correlating this on-site information with basin slope, elevation, and size data from topographic maps, the necessary site parameters were estimated and seasonal (May to October) pan evaporation was computed for each.

The seasonal lake evaporation was then computed by applying the appropriate Richardson equation. Annual evaporation for each site was estimated by applying the seasonal/annual factor from Weather Bureau Technical Publication No. 37 (Figure 5). Lake evaporation was also calculated from the annual pan coefficients given in Technical Publication No. 37 (Figure 6). The magnitude of error introduced by use of these two factors is unknown, however, no better procedure is available. Meaningful pan data are limited to approximately May to October at most Utah sites. The lake/pan coefficients are widely recognized as being quite accurate on an annual basis and no attempt was made to determine the much less reliable monthly coefficients.

Effect of reservoir depth

Large variations in reservoir depth result in significant monthly variations in evaporation. Due to the difference in heat storage capacity, the surface temperature increase during early summer on a deep reservoir will lag behind the mean air temperature much more than on a very shallow reservoir. Harding (1962) compared evaporation on two adjacent lakes in Nevada; one 15 feet and the other 200 feet deep. A summary of the results is as follows:

Period	Deep Lake	Shallow Lake	Ratio Deep/Shallow
Mar.-Aug.	1.88	3.03	.62
Sept. Feb.	2.14	.95	2.25
May-Oct.	2.45	3.31	.74
Total for year	4.02	3.98	1.01

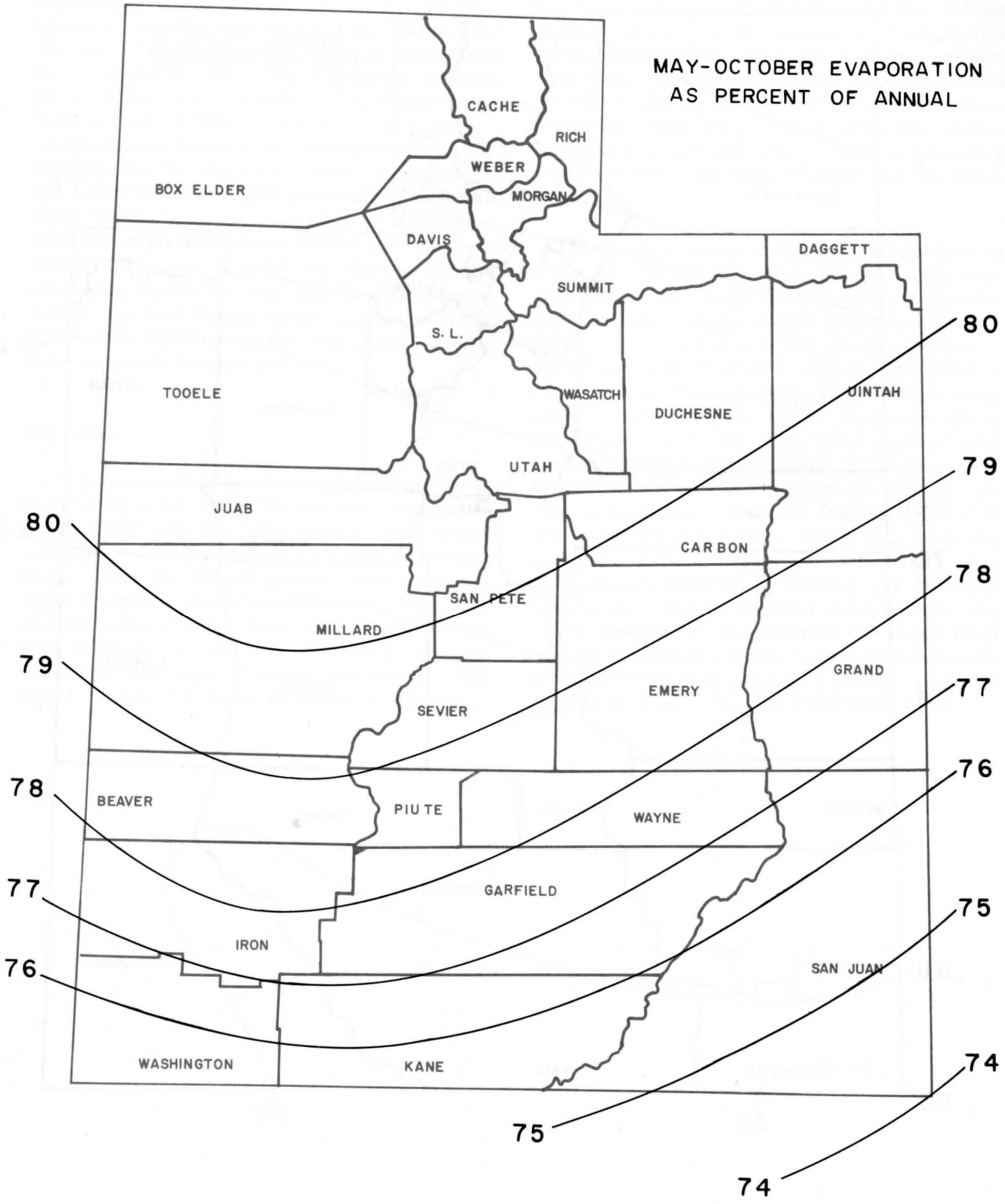

Figure 5. May-October evaporation as percent of annual in Utah (Utah iso. map).

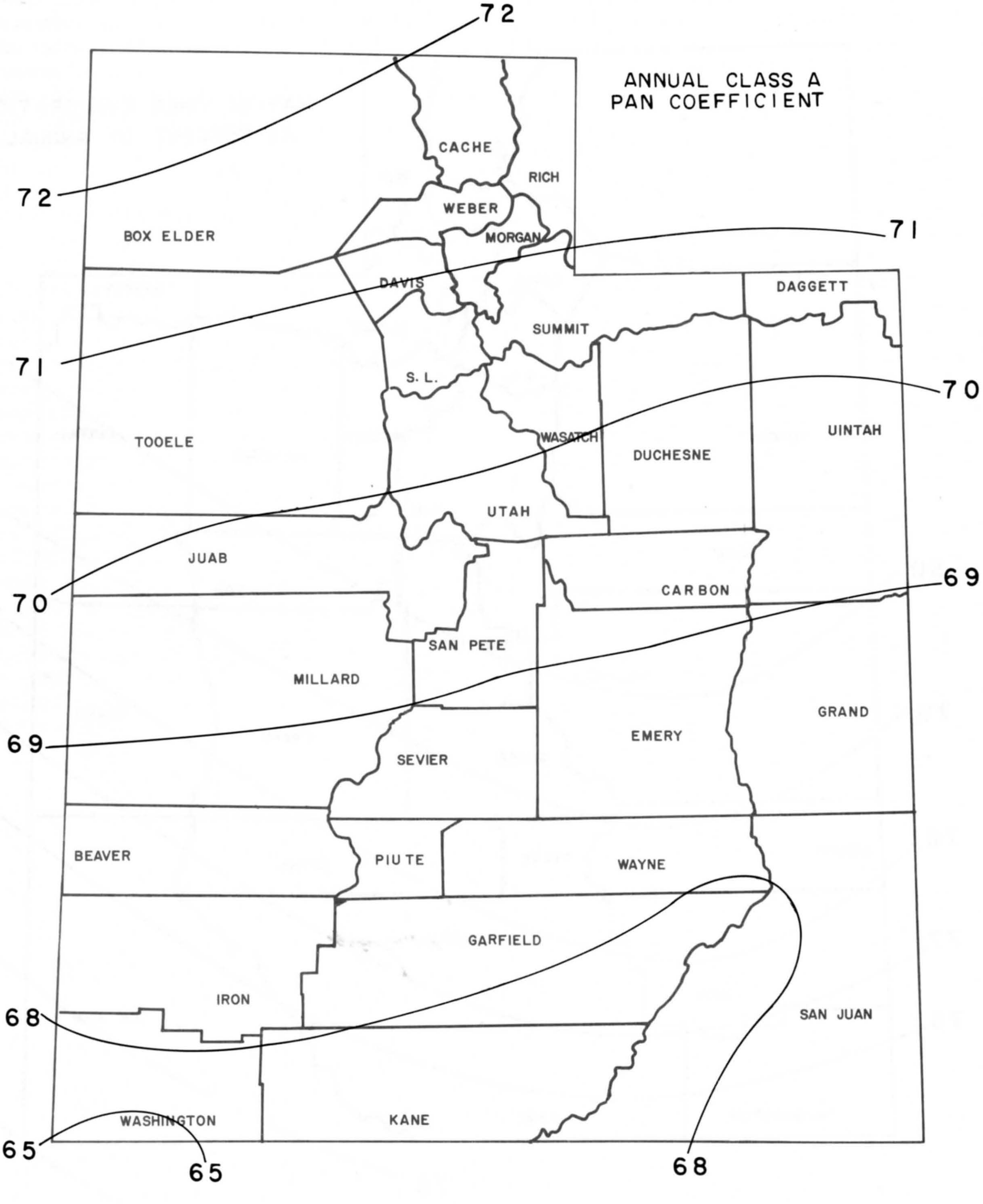

Figure 6. Annual Class A pan coefficient (Utah iso. map).

The summary shows surprising equality on an annual basis, a three-fourths ratio for the May-October season used in this report and much greater variation during the fall-winter period. The Harding analysis suggests that reservoir depth should be considered in estimating evaporation for time periods other than complete years. Unfortunately there is not sufficient data to develop such a relationship for depths other than those compared by Harding. The lake evaporation estimates produced in this report are based upon pan to lake coefficients which in turn were developed from studies on relatively deep lakes (Lake Hefner and Mead for example). Because of this, the May to October evaporation figures for very shallow impoundments such as the Bird Refuge areas may be somewhat higher than reported herein. The annual figures, however, should be more accurate.

Salt water

The evaporation equations described previously do not apply to salt water. The estimated evaporation on Great Salt Lake was taken from previous special studies of the lake. Such estimates cover a rather wide range. There are several factors which make salt water evaporation estimates more difficult than those on other bodies of water. Evaporation varies not only with climatic factors but also with salinity. Since the lake salinity varies significantly with stored volume, this factor is related to lake stage. Pan data are difficult to interpret since at certain times condensation occurs on the lake while evaporation is occurring from fresh water. Another difficult factor to evaluate is the variability of evaporation across the lake. Warm dry winds from the northwest cause high evaporation rates as the air begins to cross the lake, but by the time this air mass reaches evaporation pans near the southeast shore the relative humidity has increased greatly, thereby decreasing evaporation at these pans (Dickson and McCullom, 1965).

Long term average estimates of evaporation on Great Salt Lake can be misleading because of the large variation with lake stage as well as climate. Fletcher (1974) reports a range of 29.5 inches to 45 inches during the period of record. The lake stage, however, during the summer of 1974 is about 4201 which is rather close to the average for the period of record (4201.7). Because of the lack of agreement among researchers as to the long term average lake evaporation, the traditional Adams (1934) estimate of 37.7 inches was used in the inventory. This is quite close to estimates of Peck and Dickson (1965) of 34 inches plus the groundwater inflow. It is much less than the estimate suggested by eddy flux measurements reported by Dickson and McCullom (1965) of 50.8 inches for the summer only (although the winter condensation may decrease this figure when extending to an annual basis). It is apparent that much additional research is needed to develop a reliable evaporation function for Great Salt Lake.

UTAH EVAPORATION SUPPRESSION MODEL

Suppression Methods

As indicated in the literature review, past attempts at evaporation suppression have essentially been limited to two methods: (1) Maintenance of a monolayer film on the water surface of medium or large impoundments, or (2) installation of more permanent wind resistant floating covers on small ponds.

There are other factors which are important to consider during the planning stage for new reservoirs. These include site selection which will minimize the surface area/volume ratio, wind conditions, perimeter vegetation, and the possiblity of substituting groundwater aquifers for surface storage. Other considerations, however, often dictate a particular surface storage site. Once the impoundment is constructed, little can be done with these parameters except perhaps to improve wind breaks around reservoirs which are small enough for perimeter conditions to exert a significant influence on evaporation. Another possibility of this type is adding dikes to limit the surface area to deeper areas which store more water than they evaporate. This treatment is worthwhile only in reservoirs with large shallow areas such as Utah Lake.

One major purpose of this project is to estimate the statewide potential in Utah for increasing the water supply by suppressing evaporation. The major effort to date in this regard has been as follows:

1. Inventory existing surface storage.
2. Estimate the present average evaporation rates.
3. Estimate the percent suppression achievable with a monolayer film on each impoundment in Utah.
4. Estimate the suppression achievable on small ponds with floating covers.

Items one and two, the reservoir inventory and normal evaporation estimates, have been described in previous sections. Items three and four will be addressed later in this chapter. The following section, however, describes a different approach which will be pursued during the second phase of this project.

Reservoir Destratification

During the progress of the monolayer film research, the writers became aware of a completely different approach to evaporation suppression which appears to have important potential and which surprisingly, is not treated at all in the literature.

Examination of Dalton's basic evaporation equation reveals that evaporation is a function of two primary variables, the water to air vapor pressure gradient which releases water vapor from the surface and the wind which moves the vapor away. The effect of a monolayer film is actually the opposite of what is desired in terms of the vapor pressure gradient; that is, by suppressing the cooling effect of evaporation, the surface water temperature increases above normal, thereby causing very rapid evaporation (a higher gradient) when the film is broken, resulting in a decreased net savings.

The ideal suppression method would be one that would decrease rather than increase the surface temperature, thereby decreasing the vapor pressure gradient. A method which appears to have this capability in any temperature stratified body of water is that of mixing (destratifying) the water. A reliable and low cost way of doing this is to continuously pump air to the bottom of the reservoir at a sufficient rate to set up mixing currents with vertical components. This procedure has been used for several years on at least 23 reservoirs in the United States and several other countries in connection with water quality improvement objectives. It apparently has never been evaluated, however, in terms of its potential for suppressing evaporation.

Preliminary calculations indicate that this procedure may be capable of suppressing considerably more evaporation on many reservoirs than will a monolayer film. Its effect is relatively independent of wind except on shallow reservoirs where wind already mixes the water. The savings will increase with thermal stratification of the reservoir. It may not be effective at all on a shallow reservoir which has little vertical temperature gradient; but deeper reservoirs have a temperature difference between surface and bottom of as much as 25°F. Most of the gradient is relatively close to the surface so that after mixing to a zero gradient, the surface temperature should be closer to the previous bottom temperature than to the original surface temperature.

Another factor which lends optimism to the potential for destratifying is the economic picture. Preliminary evaluation indicates a cost much less (perhaps an order of magnitude less) than that of maintaining a monolayer film. The energy required is only that represented by vertically moving a mass represented by the difference in density of the stratified water, not the total weight of water moved. A further benefit is that at many reservoirs, the improvement in water quality (dissolved oxygen and algae reduction for example) may well justify the cost of destratification with evaporation suppression being considered a free side effect.

Because of the apparently important potential of this procedure, and the total lack of previous research on the evaporation suppression aspects of the concept, a significant portion of the effort expended during the second year of this project will be directed to this method of evaporation suppression.

Several evaporation pans will be maintained at different temperatures in order to varify the effect on evaporation of varying the water surface temperature. These results will be extended to lake evaporation by developing an estimated surface temperature decrease model which considers reservoir surface area, depth, capacity, and existing temperature profile. Data on, before, and after mixing temperature profiles will be gathered from owners of reservoirs which have previously been destratified for quality projects. The actual temperature profile will also be measured monthly at several representative reservoirs in Utah. The results will then be analyzed and extended to the balance of the Utah reservoir inventory. The reservoir inventory and evaporation estimates developed during this initial phase of the project and reported in this volume will provide an important basis for the destratification suppression model just as it is used in the balance of this section as a basis for the monolayer suppression model.

Monolayer Film Suppression Model

Model A

As indicated in the literature review, there has been a relatively large amount of research done on evaporation suppression projects at particular reservoirs but very few researchers have attempted to develop a model to extend these results to other reservoirs. The often quoted Australian guidelines are as follows:

1. Savings up to 40 percent or more can be expected with winds up to ∼ 5 mph.
2. Savings of 10-20 percent can be expected with winds up to ∼ 10 mph, though occasionally savings may be somewhat less, depending upon prevailing conditions.
3. With winds persistently in excess of 15 mph, the savings approach zero.

These general guidelines are difficult to translate into a rigorous mathematical model. What do the phrases "up to" and "persistently in excess of" mean in terms of average or frequency distribution of wind speed? Also, there is the question of how reliable the Australian guidelines are in the United States in view of the rather low suppression rates achieved by USBR projects.

In order to analyze these equations the results of previous field trials for which both percent suppression and average wind speed are available, were plotted as shown in Figure 7 (Model A). The data include results of three USBR projects — Sahuaro, Cachuma, and Hefner; a project at Stanford University (Franzini, 1961); and the Australian guidelines. There are several other field trials described in the literature but unfortunately most of them didn't include information on average wind during the tests.

In addition to portraying percent suppression as a function of average wind speed, Figure 7 includes the results of the frequency distribution analysis described previously.

The Australian guidelines were interpreted in a relatively conservative fashion as follows:

The 20 to 40 percent suppression points were plotted at 2.5 mph (the guideline suggests up to 5 mph). With this mid range interpretation, Figure 7 suggests that at a reservoir with an average wind of 2.5 mph, winds over 5 mph would occur only 12 percent of the time. Similarly, the 10 to 20 percent suppression points were plotted at an average wind speed of 7.5 mph (guideline is up to 10 mph). At this sort of location one can expect winds over 10 mph again at 12 percent of the time. The upper limit of the Australian guidelines suggests some suppression up to 15 mph, however, Figure 7 shows the suppression approaching zero at an average wind of 10-11 mph. This average suggests winds over 15 mph only 7 to 8 percent of the time.

If one conceives these rather conservative modified Australian upper and lower limits as representing reservoir sites with respectively best to worst exposure conditions, the curves bracketing the range of probable suppression as shown in Model A result.

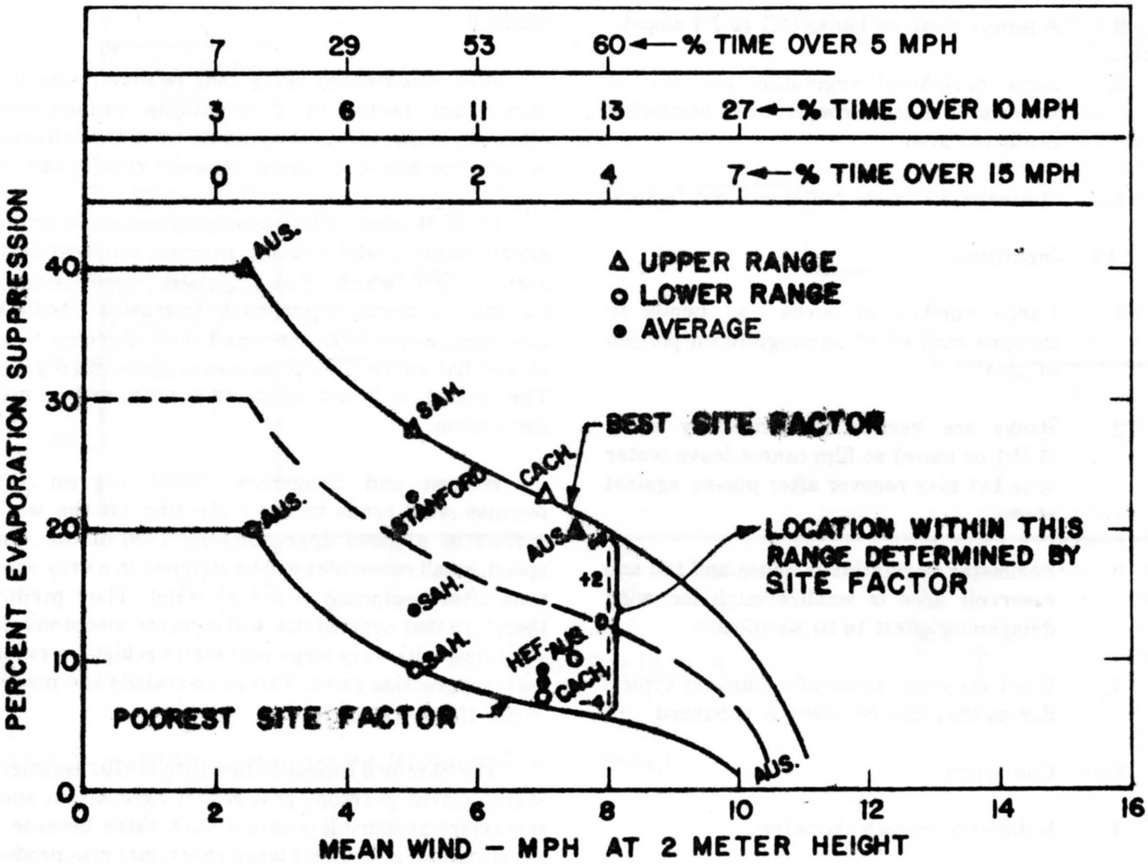

Figure 7. Monolayer suppression—Model A.

Examination of the data points for the four U.S. field trails indicates that all are within the range defined by the Australian guidelines. It would appear then, that the Australian-U.S. results are not inconsistent as some researchers have suggested, at least within the context of the "up to" interpretation suggested by this analysis.

Site factor

The exposure index is defined conceptually as a means of evaluating all parameters which affect suppression efficiency except for average wind speed (the primary variable of Model A) and reservoir size (the only variable of Model B).

From a practical standpoint, the index could include only those parameters for which data can be obtained and for which some idea of that parameter's influence on film efficiency is known.

Site factor definition

Parameters considered:

1. Perimeter shape
2. Bank slopes
3. Vegetation importance as wind break around perimeter
4. Drainage wind influence

Index: Begin with index magnitude of 5 and change as follows for each parameter.

+1 for each parameter which increases film effectiveness

0 for each average condition

-1 for each parameter which decreases film coverage or effectiveness

Standards for evaluation:

(0) Average:

1. Some irregularity in shoreline and some side canyons but minor in relation to total size

2. Average slope on banks (1:1 to 2:1 slope)

3. Some peripheral vegetation but size of water area is large compared to perimeter protected area

4. Drainage winds are not significant factors

(+) Conditions:

1. Large number of coves and bends to dampen wind effect on a significant portion of area

2. Banks are vertical or extremely steep (1/2:1 or more) so film cannot leave water area but may recover after pile-up against shore

3. Perimeter vegetation is dense and tall and reservoir area is small enough for wind dampening effect to be significant

4. Wind direction reversal occurs on typical day so that film recovery is enhanced

(-) Conditions:

1. Relatively smooth shoreline

2. Slope less than 3:1 on majority of perimeter so that film pile-up will occur on banks and be lost

3. Perimeter vegetation is sparse, low, or size of water area is extremely large so that wind break effect is negligible

4. Strong drainage winds in single direction on typical day

Data for evaluation of the site factor for each impoundment was obtained from site visits, topographic maps, and/or personal knowledge of the research team. The up-slope surrounding basin was evaluated in terms of size and slope from topographic maps. The index includes some factors which cannot be determined without a site visit. For minor reservoirs which were not actually visited, these parameters were assumed to have average values.

The site factor index is, or course, somewhat subjective, but is considered to represent as good an estimate as possible, without detailed study of each site, of the proper location between the upper and lower limits defined by Model A.

Model B

Most researchers agree that reservoir size is a significant factor in determining suppression efficiency; however, few agree on what the influence is and some arrive at almost opposite conclusions.

W. C. Hughes (1968) developed a monolayer film effectiveness model relating percent suppression to surface area which shows highest suppression at minimum size with suppression decreasing rapidly as size increases to 1000 acres and then changing to an almost flat curve as size increases above 3000 acres. This model is based upon data with rather poor correlation.

Hansen and Skogerboe (1964) suggest that because wind tends to move the film off the water surface at a speed approximately 1/30 of the wind speed, small reservoirs will be stripped in a very short time after beginning of a high wind. They predict, therefore that suppression will increase monotonically with size, with very large reservoirs achieving rather high suppression rates. This is essentially the inverse of the Hughes function.

The Stanford Research Institute (1970) assumes a still different position. This report agrees that small reservoirs produce low suppression rates because of rapid stripping, but that large reservoirs also produce low rates because the long fetches allow larger waves to form, thereby inundating and destroying the film prior to the stripping action. SRI suggests an optimum size of 5,000 to 20,000 acres with reductions at each end of this range.

The suppression/area function as used for this project follows the form of equation suggested by the SRI report, as shown in Figure 8. The optimum range, however, is set at 100 to 10,000 acres for the following reasons: Model B is to be used only to provide a correction (reduction) factor to suppression rates taken from the basic Model A. Since all the empirical data upon which Model A are based falls within the 100 to 10,000 acre range (the Australian reservoirs were about 300 acres), there appears to be no justification for using higher suppression rates at the higher size range suggested by SRI. The exact location and size of the penalty factors are somewhat arbitrary but until additional data are available this crude model will at least provide an approach to a rational form of the function. The actual function is obviously a smooth curve but the discrete steps are used here to emphasize the gross nature of the data upon which it is based.

The procedure then for estimating the suppression rate at any reservoir in Utah is a follows:

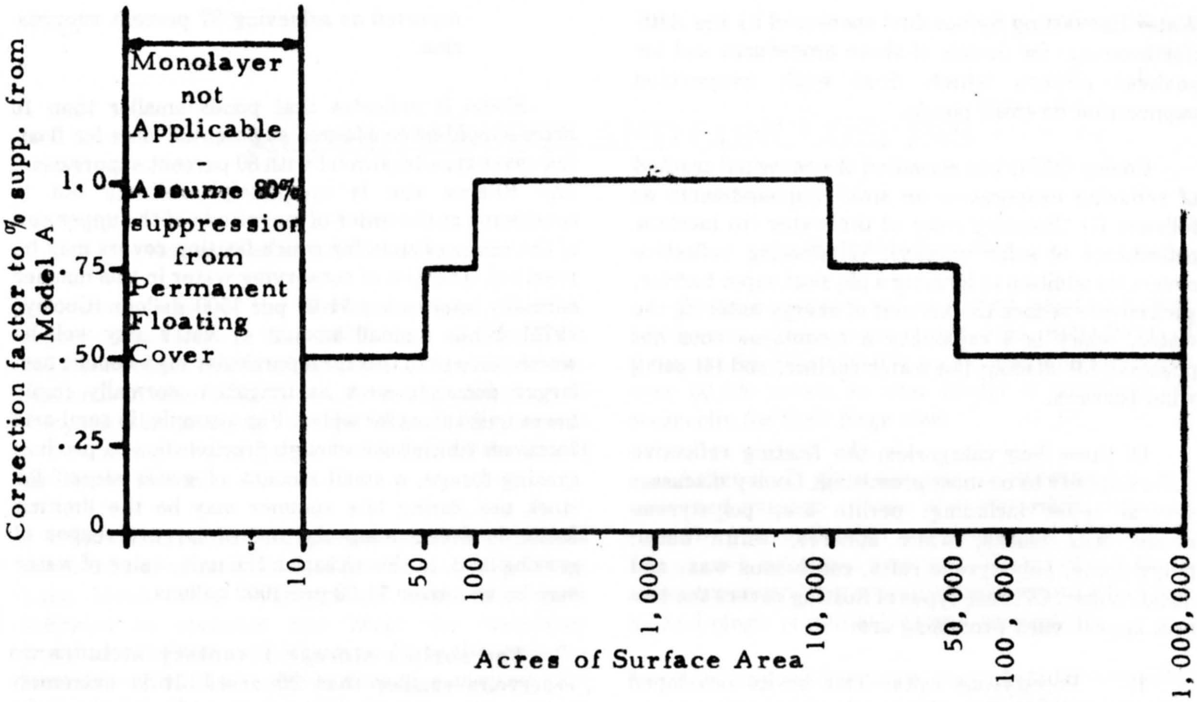

Figure 8. Suppression correction for reservoir size—Model B.

1. Determine average of May to October wind speed at the 2-meter height. If the wind data or estimated wind are based upon pan data, multiply by 2.1 to convert to 2-meter reservoir wind (see Utah wind pattern section for derivation of this factor).

2. Determine the site exposure factor as defined in the previous section.

3. Enter Model A with the 2-meter wind speed and determine the range of suppression for this wind speed; then use the exposure factor to define the proper location within this range and select the suppression rate by moving horizontally from this point.

4. Multiply percent suppression from Model A by the proper size correction factor from Model B to calculate final percent suppression for May to October treatment period.

5. If reservoir size is less than 10 acres, ignore Model A. A monolayer film is not feasible in the range, but a floating cover type of treatment may be practical and will achieve at least 80 percent suppression.

Small Ponds

There appears to be general agreement among researchers that maintenance of a monolayer film on very small reservoirs is not practical, or at least that this is not the best way of suppressing the evaporation on them. Because of the rapid stripping action on very short fetches the percent coverage is usually very low. If continuous replacement of the film is provided, the quantity of alkanol per acre becomes high in relation to that required on larger impoundments.

In the southwestern part of the U.S. extensive research has been done both on monolayer and other more permanent types of evaporation suppression covers for small reservoirs. Much of this research has been done by the Agricultural Research Service laboratory at Phoenix and at the University of Arizona at Tucson. The work with floating covers is a natural part of the water harvesting research being done in Arizona and several other areas. If water is valuable enough to justify soil treatment of micro watershed to increase runoff, it follows that it is valuable enough to protect from evaporation loss after collection.

The various water harvesting techniques being used around the world will not be discussed here. The reader is referred to the Proceedings of the 1974

Water Harvesting Symposium sponsored by the ARS (forthcoming) for details of these procedures and for several papers which deal with evaportion suppression on small ponds.

Cooley (1974) has classified the principal method of reducing evaporation on small impoundments as follows: (1) Changing color of the water (to increase reflectance of solar energy); (2) floating reflective covers (in addition to forming a physical vapor barrier, such covers reduce the amount of energy entering the water, which is a capability a monolayer does not possess); (3) shading the water surface; and (4) using wind barriers.

Of these four categories, the floating reflective covers appear to be most promising. Cooley discusses several types including: perlite ore, polystyrene beads, wax blocks, white spheres, white butyl, polystyrene, polystyrene rafts, continuous wax, and butyl rubber. Of these types of floating covers the two that appear most promising are:

1. Polystyrene rafts—This device developed by Cluff (1972) consists of polystyrene sheets with an asphalt and gravel upper surface added for weight and weather resistance. The unites are anchored together with PVC pipe sections as clamps for wind protection. Suppression efficiencies of 95 percent were reported for this method. It has been tested in actual field trials in connection with a water harvesting project for growing grapes in the desert near Tucson. The device apparently has rather good resistance to wind.

2. Continuous wax—Cooley reports good results from melting (or allowing the sun to melt) wax and allowing it to form a thin cover on the water surface. This method is very simple, easy to repair, relatively inexpensive, and apparently has good wind resistance (although to date it has been tested only on small stock tanks). It is reported as achieving 87 percent suppression.

Model B indicates that ponds smaller than 10 acres should be considered as potential sites for floating cover type treatment with 80 percent suppression. The 10-acre size is completely arbitrary but is considered as the order of magnitude of the upper end of the range of sizes for which floating covers may be practical. The cost of conserving water in this manner normally approaches $1.00 per 1000 gallons (Cooley, 1974). While a small amount of water may well be worth more than this for a particular high benefit use, larger demands such as irrigation normally imply lower unit values for water. For example, in semi-arid locations which have enough precipitation to produce grazing forage, a small amount of water stored for stock use during late summer may be the limiting factor in determining the use of large acreages of grazing land. In this situation the unit value of water may be well over $1.00 per 1000 gallons.

The surface storage inventory includes no reservoirs smaller than 20 acres. It is extremely difficult to get accurate data on a statewide basis for farm reservoirs smaller than this, and it was not considered worthwhile to attempt extending the inventory to this range of sizes. The total volume of water evaporated in Utah from small ponds is obviously negligible in relation to that on the large impoundments; but may be very important to an individual owner of a small reservoir who is short of water late in the season. Many small ponds, in fact, lose more to evaporation than is used beneficially during a season.

Information which is of value to the owner of such a reservoir is the following:

1. An estimate of the seasonal loss can be determined from the lake evaporation depth map for Utah (see Figure 9 in the next chapter).

2. Floating covers which suppress 80 to 95 percent of evaporation are available.

MODEL RESULTS AND CONCLUSIONS

Comparison with SRI Analysis

As described in the literature review, the SRI report (Blackmer et al., 1970) had a significant negative impact on the continuation of monolayer film research in the U.S. It is interesting therefore to compare the analysis of the monolayer concept potential from the SRI report with that of the model developed herein.

The SRI percent suppression analysis consists essentially of an estimation of possible suppression on Lake Mead. This is surprising since the report indicates an optimum size range for monolayer treatment of 5,000 to 20,000 acres. They then select a reservoir with 124,000 acre surface area as a test case and extend the results (12 percent suppression derived from 14 percent idealized analysis on Lake Mead) to the entire Western U.S. In comparison to Utah reservoirs, a Lake Mead analysis would produce very unfavorable results because the average 2-meter wind on Mead is 6.7 mph while in Utah the average 2-meter wind on all manmade or regulated lakes in the inventory is 4.05 mph (even after 2.1 correction factor to increase pan winds for surface roughness as well as height). In the most important category,those over 1000 acres, only one reservoir in Utah has as high an average wind as Mead.

If the suppression models developed in this project are applied to Lake Mead, a suppression of 14 percent is obtained from Model A which is then reduced to 7 percent by Model B because of the long fetch for wave development; therefore, this analysis predicts worse results than SRI on Lake Mead, but considerably better results of typical Utah reservoirs. The average suppression produced by the Utah model is as follows:

Manmade or Regulated Lakes	Number (each)	Percent Suppression
over 1000 acres	29	20.7
100 to 1000 acres	67	21.4
under 100 acres	43	13

Statewide Summary

Of the reservoirs and regulated lakes with over 1,000 acres of maximum water area, only three of these are 10,000 to 50,000 acres, and only three are over 50,000 acres; so that Model B penalized six reservoirs for their large size.

Appendix D gives the percent suppression, and estimated average volume of water which could be saved by May to October maintenance of a monolayer film on each individual reservoir. The statewide totals are summarized by reservoir categories in Table 6 and by hydrologic region in Tables 7 through 16.

The statewide summary shows that the over 1000 acre manmade (or natural but regulated) category is by far the predominant category in terms of potential salvageable volume. It includes 155,800 acre feet or 79 percent of the salvageable water (and 83 percent of the natural evaporation).

The managed wetlands include a significant amount of salvageable water (28,000 acre feet). These are primarily located on the east shore of Great Salt Lake.

The inclusion of the natural lake categories in the model was somewhat academic because the probability of suppression with a chemical film on such bodies of water would certainly be a last resort after all possible suppression on artificial lakes is accomplished. They were included in the model, however, in order to provide data to at least evaluate the potential from a technical standpoint. The summary indicates that suppression on such waters is even less likely than one might intuitively suppose since the statewide salvageable total for these categories is negligible in comparison to the manmade categories. The summary given in Table 6 indicates that the average annual evaporation in Utah for all types of open water included in the inventory (439,000 acres) is 3.8 feet or 1,699,000 acre feet. The suppression model estimates that 195,300 acre feet of this water could be salvaged. This is 11 percent of the annual or 14 percent of the seasonal (the period of film maintenance) evaporation.

The hydrologic basin summaries indicate the following:

Table 6. Utah summary of evaporation and monolayer suppression potential.

	Natural lakes over 1000 acres	Surface Area (ac/ft) Max.	Surface Area (ac/ft) Mean	Lake Evaporation (ac/ft) Annual	Lake Evaporation (ac/ft) Seasonal	Potential Savings (ac/ft)	Number of Reservoirs or lakes
1	Natural lakes over 1000 acres	1,330	1,064	1,397	1,117	246	1
2	Natural lakes 100-1000 acres	2,049	1,791	4,894	3,859	802	9
3	Natural lakes under 100 acres	1,939	1,789	3,225	2,555	342	39
4	Unmanaged wetlands	3,828	3,197	11,283	9,018	1,975	16
5	Man-made or regulated lakes over 1000 acres	454,667	355,694	1,419,725	1,102,471	155,847	29
6	Man-made or regulated lakes 100-1000 acres	22,569	17,280	46,681	36,801	7,869	67
7	Man-made or regulated lakes under 100 acres	2,831	2,151	4,894	3,846	559	43
8	Federal wetlands	28,133	28,133	110,039	88,031	12,864	2
9	State wetlands	18,029	18,029	67,663	54,117	10,151	11
10	Private wetlands	7,639	7,639	29,378	23,503	4,667	10
	Total	543,014	436,765	1,699,179	1,825,318	195,318	227

Table 7. Evaporation and suppression summary for the Weber River Basin.

BASIN NUMBER 1 GSL DESERT RESERVOIR TYPE		SURFACE AREA MAX (AC FT)	SURFACE AREA MEAN (AC FT)	LAKE EVAPORATION ANNUAL (AC FT)	LAKE EVAPORATION SEASONAL (AC FT)	POTENTIAL SAVINGS (AC FT)
0	GREAT SALT LAKE	1580000	1150000	3600000	3600000	0
1	NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2	NATURAL LAKE 100 TO 1000 ACRE	0	0	0	0	0
3	NATURAL LAKE UNDER 100 ACRE	90	90	331	265	18
4	UNMANAGED WETLANDS	0	0	0	0	0
5	MANMADE LAKE OVER 1000 ACRE	0	0	0	0	0
6	MANMADE LAKE 100 TO 1000 ACRE	851	508	1993	1586	261
7	MANMADE LAKE UNDER 100 ACRE	126	82	288	230	16
8	FEDERAL WETLANDS	7200	7200	37275	29820	2386
9	STATE WETLANDS	1790	1790	7678	6142	912
10	PRIVATE WETLANDS	0	0	0	0	0
	FRESH WATER TOTALS	10057	9670	47565	38044	3593
	SALT WATER TOTALS	1580000	1150000	3600000	3600000	0
	PERCENT OF STATE TOTALS (FRESH WATER ONLY)	1.8	2.2	2.8	2.9	1.8

Table 8. Evaporation and suppression summary for the Bear River Basin.

BASIN NUMBER 2 BEAR RIVER RESERVOIR TYPE	SURFACE AREA MAX	(AC FT) MEAN	LAKE EVAPORATION ANNUAL	(AC FT) SEASONAL	POTENTIAL SAVINGS (AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	0	0	0	0	0
3 NATURAL LAKE UNDER 100 ACRE	350	350	869	695	99
4 UNMANAGED WETLANDS	1527	1527	5237	4190	970
5 MANMADE LAKE OVER 1000 ACRE	87493	86578	261533	209226	27648
6 MANMADE LAKE 100 TO 1000 ACRE	1674	1423	4106	3285	786
7 MANMADE LAKE UNDER 100 ACRE	130	116	313	250	28
8 FEDERAL WETLANDS	20933	20933	72764	58211	10478
9 STATE WETLANDS	2545	2545	6890	7112	1539
10 PRIVATE WETLANDS	6327	6327	24333	19466	3879
FRESH WATER TOTALS	120979	119799	376044	302435	45427
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	22.2	27.3	22.2	22.8	23.2

Table 9. Evaporation and summary for the Weber River Basin.

BASIN NUMBER 3 WEBER RIVER RESERVOIR TYPE	SURFACE AREA MAX	(AC FT) MEAN	LAKE EVAPORATION ANNUAL	(AC FT) SEASONAL	POTENTIAL SAVINGS (AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	0	0	0	0	0
3 NATURAL LAKE UNDER 100 ACRE	114	114	184	147	20
4 UNMANAGED WETLANDS	315	315	1118	895	233
5 MANMADE LAKE OVER 1000 ACRE	5420	4871	16594	13275	3394
6 MANMADE LAKE 100 TO 1000 ACRE	1915	1671	5551	4441	1053
7 MANMADE LAKE UNDER 100 ACRE	127	113	174	139	20
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	6298	6298	22838	18271	3542
10 PRIVATE WETLANDS	192	192	738	591	118
FRESH WATER TOTALS	14381	13574	47197	37758	8379
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	2.6	3.1	2.8	2.8	4.3

Table 10. Evaporation and suppression summary for the Jordan River Basin.

BASIN NUMBER 4 JORDAN RIVER RESERVOIR TYPE	SURFACE AREA MAX (AC FT)	SURFACE AREA MEAN (AC FT)	LAKE EVAPORATION ANNUAL (AC FT)	LAKE EVAPORATION SEASONAL (AC FT)	POTENTIAL SAVINGS (AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	400	400	1633	1307	340
3 NATURAL LAKE UNDER 100 ACRE	80	80	117	93	15
4 UNMANAGED WETLANDS	210	210	816	653	93
5 MANMADE LAKE OVER 1000 ACRE	102275	66024	292874	234299	24828
6 MANMADE LAKE 100 TO 1000 ACRE	694	482	1677	1342	287
7 MANMADE LAKE UNDER 100 ACRE	0	0	0	0	0
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	4692	4692	16520	14816	3014
10 PRIVATE WETLANDS	1120	1120	4307	3446	670
FRESH WATER TOTALS	109471	73008	317944	255955	29246
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	20.1	21.2	18.8	19.3	14.9

Table 11. Evaporation and suppression summary for the Sevier River Basin.

BASIN NUMBER 5 SEVIER RIVER RESERVOIR TYPE	SURFACE AREA MAX (AC FT)	SURFACE AREA MEAN (AC FT)	LAKE EVAPORATION ANNUAL (AC FT)	LAKE EVAPORATION SEASONAL (AC FT)	POTENTIAL SAVINGS (AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	150	150	431	345	83
3 NATURAL LAKE UNDER 100 ACRE	126	100	173	134	22
4 UNMANAGED WETLANDS	127	87	326	260	23
5 MANMADE LAKE OVER 1000 ACRE	22966	10806	37645	29748	4969
6 MANMADE LAKE 100 TO 1000 ACRE	5364	3717	10313	8158	1329
7 MANMADE LAKE UNDER 100 ACRE	210	154	387	304	34
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	2160	2160	8312	6649	930
10 PRIVATE WETLANDS	0	0	0	0	0
FRESH WATER TOTALS	31103	17174	57587	45599	7389
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	5.7	3.9	3.4	3.4	3.8

Table 12. **Evaporation and suppression summary for the Cedar-Beaver Basin.**

BASIN NUMBER 6 CEDAR-BEAVER	SURFACE AREA		LAKE EVAPORATION		POTENTIAL
	MAX	MEAN	ANNUAL	SEASONAL	SAVINGS
RESERVOIR TYPE	(AC FT)		(AC FT)		(AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	777	622	1877	1445	231
3 NATURAL LAKE UNDER 100 ACRE	100	76	144	113	16
4 UNMANAGED WETLANDS	20	13	65	51	2
5 MANMADE LAKE OVER 1000 ACRE	0	0	0	0	0
6 MANMADE LAKE 100 TO 1000 ACRE	1576	1272	4077	3161	597
7 MANMADE LAKE UNDER 100 ACRE	265	193	484	374	50
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	0	0	0	0	0
10 PRIVATE WETLANDS	0	0	0	0	0
FRESH WATER TOTALS	2738	2176	6647	5144	896
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	0.5	0.5	0.4	0.4	0.5

Table 13. **Evaporation and suppression summary for the Uintah Basin.**

BASIN NUMBER 7 UINTAH BASIN	SURFACE AREA		LAKE EVAPORATION		POTENTIAL
	MAX	MEAN	ANNUAL	SEASONAL	SAVINGS
RESERVOIR TYPE	(AC FT)		(AC FT)		(AC FT)
1 NATURAL LAKE OVER 1000 ACRE	1330	1064	1397	1117	246
2 NATURAL LAKE 100 TO 1000 ACRE	722	619	953	762	148
3 NATURAL LAKE UNDER 100 ACRE	648	597	754	603	88
4 UNMANAGED WETLANDS	1599	1015	3561	2849	643
5 MANMADE LAKE OVER 1000 ACRE	60530	43028	128946	103157	21411
6 MANMADE LAKE 100 TO 1000 ACRE	4750	3682	7864	6291	1646
7 MANMADE LAKE UNDER 100 ACRE	743	568	917	733	110
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	0	0	0	0	0
10 PRIVATE WETLANDS	0	0	0	0	0
FRESH WATER TOTALS	70322	50573	144392	115513	24292
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	12.9	11.5	8.5	8.7	12.4

Table 14. Evaporation and suppression summary for the West Colorado Basin.

BASIN NUMBER 8 WEST COLORADO RESERVOIR TYPE	SURFACE AREA MAX (AC FT)	SURFACE AREA MEAN (AC FT)	LAKE EVAPORATION ANNUAL (AC FT)	LAKE EVAPORATION SEASONAL (AC FT)	POTENTIAL SAVINGS (AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	0	0	0	0	0
3 NATURAL LAKE UNDER 100 ACRE	401	350	547	423	55
4 UNMANAGED WETLANDS	0	0	0	0	0
5 MANMADE LAKE OVER 1000 ACRE	12158	9656	28513	22456	4804
6 MANMADE LAKE 100 TO 1000 ACRE	2860	2269	5207	4093	892
7 MANMADE LAKE UNDER 100 ACRE	885	653	1285	1005	171
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	544	544	1425	1126	214
10 PRIVATE WETLANDS	0	0	0	0	0
FRESH WATER TOTALS	16848	13472	36977	29104	6136
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	3.1	3.1	2.2	2.2	3.1

Table 15. Evaporation and suppression summary for the South and East Colorado basin.

BASIN NUMBER 9 S. AND E. COLORADO RESERVOIR TYPE	SURFACE AREA MAX (AC FT)	SURFACE AREA MEAN (AC FT)	LAKE EVAPORATION ANNUAL (AC FT)	LAKE EVAPORATION SEASONAL (AC FT)	POTENTIAL SAVINGS (AC FT)
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	0	0	0	0	0
3 NATURAL LAKE UNDER 100 ACRE	0	0	0	0	0
4 UNMANAGED WETLANDS	0	0	0	0	0
5 MANMADE LAKE OVER 1000 ACRE	163825	114731	653620	490310	68793
6 MANMADE LAKE 100 TO 1000 ACRE	1095	875	2250	1687	357
7 MANMADE LAKE UNDER 100 ACRE	264	211	809	631	107
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	0	0	0	0	0
10 PRIVATE WETLANDS	0	0	0	0	0
FRESH WATER TOTALS	165184	115817	656678	492628	69256
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	30.3	26.4	38.6	37.1	35.3

Table 16. Evaporation and suppression summary for the Lower Colorado Basin.

BASIN NUMBER 10 LOWER COLORADO RESERVOIR TYPE	SURFACE AREA		LAKE EVAPORATION		POTENTIAL SAVINGS (AC FT)
	MAX	MEAN (AC FT)	ANNUAL	SEASONAL (AC FT)	
1 NATURAL LAKE OVER 1000 ACRE	0	0	0	0	0
2 NATURAL LAKE 100 TO 1000 ACRE	0	0	0	0	0
3 NATURAL LAKE UNDER 100 ACRE	30	30	106	82	9
4 UNMANAGED WETLANDS	30	30	160	120	11
5 MANMADE LAKE OVER 1000 ACRE	0	0	0	0	0
6 MANMADE LAKE 100 TO 1000 ACRE	1790	1381	3643	2757	661
7 MANMADE LAKE UNDER 100 ACRE	81	61	237	180	23
8 FEDERAL WETLANDS	0	0	0	0	0
9 STATE WETLANDS	0	0	0	0	0
10 PRIVATE WETLANDS	0	0	0	0	0
FRESH WATER TOTALS	1931	1502	4146	3136	704
PERCENT OF STATE TOTALS (FRESH WATER ONLY)	0.4	0.3	0.2	0.2	0.4

1. **Great Salt Lake Desert:** There appears to be little potential for salvage by evaporation suppression in this very large region. The inventory shows a total of 10,000 acres of fresh water, 88 percent of which is federal and state managed wetlands. The model estimates 3600 acre feet of water could be salvaged (2 percent of the state total) most of which is at Fish Springs, a federal waterfowl management area, and Locomotive Springs, a state waterfowl management area.

The average evaporation on Great Salt Lake is indicated as 3,600,000 acre feet. This is much greater than the 1944 to 1970 average of 2,493,000 developed by Steed (1972) because the lake level was well below average during the 1944 to 1970 period. It should be rather close to the 1974 evaporation, however, because lake level is within one foot of the historic average stage (based on the entire record beginning in 1850).

The suppression model does not apply to salt water and therefore no suppression is indicated. Efforts to control the level of Great Salt Lake by evaporation suppression would not only be completely unreasonable from an economic standpoint but may also be counter-productive in terms of total water supply for Utah. So much water vapor is added to the air mass as it passes over the lake, that any significant decrease in lake evaporation would decrease the precipitation in parts of the Wasatch Front. For this reason, evaporation from Great Salt Lake (and to a much smaller extent other major lakes) should not be conceived totally as a loss in the water supply picture.

2. **Bear River Basin:** This basin includes 27 percent of the average fresh water surface area of the state, 23 percent of the evaporation, and 23 percent of the potential savings by the monolayer method (45,400 acre feet). This is the second largest potential salvage area in the state (exceeded only by the basin which includes Lake Powell).

The major category for suppression potential is manmade and natural regulated lakes over 1000 acres (27,648 acre feet) primarily because it includes Bear Lake (18,223 acre feet), half of which is actually located in Idaho. The other major source of potential suppression is the Bear River Bird Refuge (10,478 acre feet) and various private duck clubs (3,879 acre feet).

A significant amount of water evaporates from the managed wetlands along the east shore of the Great Salt Lake. These wetlands are predominantly in the Bear River Delta (70 percent) but also include the Weber and Jordan Basins. The evaporation shown in these areas is only that from open water portions of the wetlands. The consumption by phreatophytes in the balance of the wetlands likely exceeds the open water loss. The State Division of Fish and Game claims that many of these wetlands experience a water shortage during the latter part of the year. The monolayer film method is undoubtedly not economically feasible for this purpose, however, other methods such as different diking concepts may be justified.

3. **Weber River Basin:** This basin includes 3.1 percent of the average water surface and 2.9 percent of the evaporation, but 4.3 percent of the salvage potential. Although the total salvage volume is relatively small, the types of reservoirs have much better than average condition characteristics for monolayer type evaporation suppression. The salvageable water is almost equally divided between higher elevation irrigation reservoirs and state managed wetlands in the Weber River Delta.

4. **Jordan River Basin:** This basin possesses 21 percent of Utah's average water surface area, 19 percent of the state's evaporation, and 15 percent of the salvageable water. This less than average salvage rate is due primarily to Utah Lake. Because of its large size and shallow depth it accounts for 86 percent of the basin's seasonal evaporation (221,738 acre feet) but the model projects only a 10 percent suppression rate. A diking project which would eliminate much of the very shallow area of Utah Lake has been proposed by the USBR as part of the Central Utah Project. Such a scheme will likely be more efficient, hydrologically and economically than a monolayer film on Utah Lake.

5. **Sevier River Basin:** This basin has 3.9 percent of the average water surface in the state, 3.4 percent of the seasonal evaporation and 3.8 percent of the salvageable water. The monolayer attractiveness conditions are close to average for the state. The salvageable volume is not large (7,000 acre feet) but in this basin, which is extremely short of water, any addition to the annual water supply would be very important.

6. **Cedar-Beaver Basin:** This extremely dry basin has only 0.5 percent of the evaporation and the potential salvageable water in the state. This volume is negligible in terms of the state inventory. However, because of the higher value of water in this basin, suppression by the monolayer method may well be economically feasible, and could be an important means of increasing sustained yield at individual reservoirs. The Enterprise Reservoir, in particular, has one of the highest estimated suppression rates in the state (27 percent).

7. **Uintah Basin:** The Uintah Basin experiences 8.7 percent of the state's evaporation, but has potential for 12.4 percent of the evaporation suppression (24,300 acre feet). Of this, 15,300 acre feet occur at Flaming Gorge (part of which is actually in Wyoming), which has an above average monolayer attractiveness rating (22 percent efficiency). It makes little sense at the present time to consider a large scale program of evaporation suppression in this basin which has a large surplus of surface water. Individual sites, however, which experience a local water shortage may well find suppression feasible.

8. **West Colorado:** This basin has 2.2 percent of the state's evaporation and 3.1 percent of the salvageable water. This indicates better than average suppression rates at several reservoirs. Forsyth Reservoir for example has a 30 percent suppression estimate due to the low wind speed and a good exposure factor. A large percent of the Lake Powell evaporation actually occurs within this basin; however, this entire lake was arbitrarily reported as being in Basin No. 9.

9. **South and East Colorado:** This basin is reported as including 26 percent of the open water surface area, 37 percent of the seasonal evaporation and 35 percent of the suppression potential. These large percentages are due entirely to the Lake Powell contribution which is 99 percent of the evaporation and 98 percent of the salvage potential. Lake Powell will lose 656,700 acre feet annually and 492,600 acre feet seasonally to evaporation. This assumes an average surface area of 115,800 acres and an annual evaporation depth of 68 inches. The potential for suppression is estimated at only 14 percent despite a good exposure factor. The model would have projected 28 percent suppression without the size penalty (long fetch for wave development).

10. **Lower Colorado:** This basin has few reservoirs of significant size. The percent of Utah evaporation and potential saving occurring here are both under .05 percent. However, the conditions for monolayer suppression on the few small reservoirs which exist are generally above average. For example, of the six manmade reservoirs in the inventory, five of them are rated at above 20 percent suppression with the highest, Baker Dam at 29 percent.

Lake Evaporation Contour Map

Figure 9 is a lake evaporation map for Utah which was developed by plotting the May to October evaporation estimates for each surface impoundment from Appendix D and then drawing the iso-lines. This map was based on more than 200 data points, many of which are at high elevations. The data points are mostly calculated rather than measured and the base for the calculations, the measured points, are mostly at low elevations. However, the higher elevation points are derived from calculations which take into account the climatological changes due to each mountainous site. For this reason, Figure 9 should give much better results than Figure 4 for interpolations to other high elevation sites.

Economic Feasibility

Although economic data on monolayer type evaporation suppression have been gathered, no detailed economic feasibility analysis will be presented in this initial volume of the project report. Such analysis should be delayed until it can be viewed in comparison with costs of other methods of salvaging water. The second report of this series will analyze suppression by destratification and will include discussion of economic feasibility by both methods.

Based on preliminary calculations, however, some general conclusions can be given at this point:

The SRI summary of USBR monolayer fields suggests that operational projects can salvage water at a cost of $25 to $30 per acre foot. The SRI analysis, based upon suppression during four summer months of each year indicates that the value of water saved will exceed the cost of suppression only in the South Pacific Basin (where water costs are high). It appears, however, that an every year concept of suppression operations is not the most realistic.

Because of weather cycles, large variations in watershed yield in Utah cause surface storage variations which are large in relation to the quantity of water which could be added by monolayer suppression. If a particular group of water users has developed a demand based roughly on the average storage in its reservoir, it makes little sense to pay for an expensive suppression operation during years when above average runoff is available. Conversely, an addition to the sustained yield during dry years should have a unit value which is much greater than the marginal value of water added during wet years.

A concept of providing a standby monolayer suppression capability but using it only as required to increase sustained yield during dry years appears to have definite economic feasibility in Utah. For example, the SRI report presents a hypothetical case where suppression of 12 percent is accomplished on a reservoir with the following costs:

Capital investment: (The major part of which is a closed circuit TV surveillance system)
$82,000

Annual Cost

Capital investment	18,000
Labor	15,000
Fuel	7,000
Chemical	72,000
Total Annual Cost	$112,000

The assumed amount of water saved (during 4 months of suppression) is 4,000 acre feet giving a salvage cost of $28 per acre foot.

Applying the same SRI costs and suppression estimate in a drought use framework would produce the following unit costs if operation only 1 of each 5 years is assumed:

Annual Costs

Capital investment	$18,000
Operation at 1/5 (94,000)	18,800
Total Annual Cost	$36,800

Total cost over 5-year period:

$$5(18{,}000) + 94{,}000 = \$184{,}000$$

Cost per acre foot if all costs are charged to the year the system is used:

$$184{,}000/4{,}000 = \$46 \text{ per acre ft}$$

Annual cost per acre foot for increasing the annual sustained yield by 4,000 acre feet:

$$36{,}800/4{,}000 = \$9.20 \text{ per acre ft}$$

A more reasonable example may be the assumption that during a 10-year period, maintenance of the sustained yield may require 4 months of operation during 1 year and 2 months of operation during another year. The following costs result:

Annual Costs:

Capital investment*	$11,644
4 month operation 1/10 (94,000)	9,400
2 month operation 1/0 (47,000)	4,700
Total Annual Cost	$25,744

*Using 7 percent interest rather than 3½ percent apparently used by SRI

Total cost:

$$116{,}440 + 94{,}000 + 47{,}000 = 257{,}440$$

Cost per acre foot of water saved:

$$257{,}440/6{,}000 = \$42.90$$

Cost per acre foot for increasing annual sustained yield by 4,000 acre feet:

$$25{,}744/4{,}000 = \$6.43 \text{ per acre foot}$$

The investment costs used in this examples are conservatively high because with such infrequent operation part of the equipment would undoubtedly be leased only during use rather than purchased. The increase in sustained yield figures are simply arbitrary assumptions and a simulation analysis of particular reservoir operations would be needed to forecast frequency and duration of operation with meaningful accuracy.

Investment by a single state agency such as the Division of Water Resources, in evaporation suppression equipment and operator training could likely produce even lower sustained yield costs. The above examples are based upon amortizing investment costs by infrequent use on a single reservoir. If several sets of portable equipment were available for use in areas where conditions justify during any particular year; and if a central large stock of chemicals were purchased at reduced bulk rates, the costs per acre foot should be less than indicated in the examples.

Summary

Evaporation estimates

In order to estimate quantities of potential evaporation suppression, an inventory of open water areas and their corresponding average evaporation depths is required. The Utah surface water inventory developed in this report includes manmade reservoirs larger than 20 acres surface area and natural lakes larger than 100 acres. An analysis of average drawdown on Utah reservoirs was made which indicates that the end of July surface area adequately represents an effective area for converting May to October evaporation depths to volumes of evaporation.

Seasonal (May-October) evaporation is computed as a function of wind, temperature, elevation, and a site exposure factor. The evaporation figures are presented for each individual impoundment and are summarized both by river basin and by type of impoundment.

Evaporation suppression quantities

This report includes estimates of potential evaporation suppression in Utah by the monolayer film method on large reservoirs and by floating covers on small ponds. A suppression model is developed which computes potential suppression as a function of average wind speed, a four parameter site factor, and reservoir size.

The estimate of salvageable water is presented for each individual impoundment and is summarized by river basin and reservoir type. The results indicate a potential statewide annual savings of 195,300 acre feet (11 percent of the total annual fresh water evaporation).

Another report in this series will analyze the salvage potential from thermal destratification of reservoirs. A preliminary evaluation of this concept suggests that it may be far superior to the monolayer film method on deep reservoirs.

Economic feasibility

A preliminary analysis of the monolayer film cost/benefit picture indicates that this treatment is not economically justified on an annual use basis, for purposes other than those having water values much higher than agricultural irrigation in Utah. However, when analyzed from drought use (sustained yield increase) basis, the monolayer film concept does appear feasible. Costs of under $10 per acre foot of increase in sustained yield appear possible.

Unit salvage costs much lower than those obtained from monolayer film suppression may also be achieved by thermal mixing.

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Appendix A

ESTIMATING SEASONAL EVAPORATION FROM CLIMATOLOGICAL DATA

by

E. Arlo Richardson[1]

Introduction

Evaporation is the process whereby water in its liquid or solid form is transferred into the gaseous state of water vapor and released into the atmosphere. The process is responsible for recycling a considerable portion of the annual precipitation back into the atmosphere.

The need for long period averages of evaporation measurement to use as indexes for the design of storage ponds, reservoirs and sewage lagoons has created the need for methods of estimating evaporation from climatological data alone.

Measuring Evaporation

The use of evaporimeters to determine an index of evaporation losses has primarily developed since the turn of the century. The most common types of evaporimeters in current use are: (a) large evaporation pans or tanks sunk into the ground or floating in the water, (b) small evaporation pans such as the standard class A pan of the National Weather Service, (c) porous porcelain bodies, and (d) porous paper wick devices. Comparison of indicated evaporation losses is best made between evaporimeters of the same type exposed under similar conditions.

The National Weather Service has accepted as standard for evaporation measurements a 4-foot pan exposed as described in "Weather Bureau Observing Handbook No. 2.—Substation Observations." Data from 34 Utah class A pan evaporation stations have been summarized and published by the National Weather Service Office of Climatology in Logan, Utah.

Actual pan evaporation of course varies with the pan environment. The location of the pan in a desert environment, an irrigated field, a forest or meadow will each produce differing amounts of evaporation by influencing such meteorological factors as the temperature of the water in the pan, the temperature and stablity of the air immediately above the surface of the water in the pan, the vapor pressure difference between the water surface, and the air, and the movement of air across the water surface.

Utah is fortunate in having data from a larger number of evaporation stations than are available in most states. Since evaporation records began, data from 36 stations have been obtained. The length of record from these stations varies from a few months to over 40 years. Short periods of record such as those at Charleston, Fishlake Ranger Station, and St. George are not the best estimates of average evaporative losses from these sites due to variations in the weather between one season and another. There are, however, other climatological data available from over 150 climatological stations in the state which are of importance in estimating or expanding the record at such stations.

Estimating Evaporation

Many equations using meteorological parameters have been tried to estimate evaporative losses but most of these equations require parameters which are not available at regular climate stations. A review of these equations indicated that the basic aerodynamic equation, first recognized by Dalton in about 1798, might have considerable potential. This equation as applied to pan evaporation is quite simple.

$$E_p = (e_s - e_a)\, a\, f(u) \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

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[1] Utah State Climatologist stationed at Logan, Utah.

E_p = the estimated pan evaporation

e_s = the saturation vapor pressure at a temperature equal to surface temperature of the water in the pan

e_a = the vapor pressure of the air immediately above the water surface

$f(u)$ = a function of the wind moving across the pan

a = a constant

A comparison of the average pan water temperature with the average air temperature for any given season showed that there was no great difference between the two values. It was therefore assumed that the vapor pressure represented by the average temperature of the air could be used to determine (e_s) in Equation (1). The vapor pressure of the air is equal to the saturation vapor pressure of the air at this temperature (e_s) multiplied by the relative humidity of the air.

Estimating Relative Humidity

Relative humidity is not measured at regular climatological stations and hence some type of estimate is required. In general the greatest rate of evaporation occurs when the relative humidity at a station is at a minimum. On the average this will occur at the time of maximum temperature during the day. In a given airmass the dewpoint at the time of occurrence of the maximum temperature will be at its maximum for the day. Figure A-1 shows the values of relative humidity which correspond to various differences between the maximum temperature and the dewpoint.

The minimum temperature is of course at least as high as the dewpoint but may be a little lower than the maximum dewpoint. The average departure of the maximum dewpoint from the minimum temperature for the evaporation season (May-Oct.) has been calculated for each first order station in the western part of the nation. These departures have been arrayed in Figure A-2. On the average the absolute values of the maximum dewpoint are not critical since an error of 5 degrees produces an error of only 3 to 5 percent in the relative himidity.

The value of the maximum dewpoint at other locations was estimated by comparing the exposure at the desired station with the exposures at the first order stations and estimating the correction which should be applied to the minimum temperature to obtain the estimated dewpoint. The range between the maximum dewpoint and the maximum temperature was then used to determine the minimum relative humidity from Figure A-1.

Pruitt found that evaporation at dry land stations when multiplied by 0.775 equaled values measured at an otherwise similar irrigated station. Milford Airport can be considered a typical dry land station with an exposure factor (EF) of about 0.78. The exposure factor has been defined as shown in Equation 2.

$$EF = (1.00 - k\frac{u}{RH}) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Using .78 as the value of EF as measured at Milford and the average wind speed and relative humidity as measured at other stations, the value of k was determined as .97. Equation (2) was then used as a comparison check on the estimated values of the relative humidity at other sites.

Calculations of Pan Evaporation

After estimating the relative humidity at each of the evaporation stations the value of (a) was calculated for Dalton's Equation using measured values of wind speed and evaporation and (e_s) as estimated from the average seasonal temperature at the station.

The value of (a) in the equation was found to be far from constant. Since the vapor pressure difference was fixed by the equation for each station the only apparent variable which could account for this variation was the wind function.

A plot of the calculated value of (a) against the wind speed (u) was made (Figure A-3) and this plot showed a high correlation. Three curves were drawn through the data, two forming an envelope and the three sets of data: Curve (1) fits the data for valley sites with wind speed less than 60 miles per day, Curve (2) fits valley sites for winds 60 to 90 miles per day, and Curve (3) fits canyon sites or sites with winds of 90 miles per day or greater.

Regression equations for these three curves were calculated and the values for a_1, a_2, and a_3 for the exposure conditions described above were thus evaluated.

$$a_1 = (2950 - 49.5u + .235u^2)\,10^{-5} \ldots\ldots\ldots\ldots (3)$$

$$a_2 = (3230 - 48.6u + .234u^2)\,10^{-5} \ldots\ldots\ldots\ldots (4)$$

$$a_3 = (3660 - 53.6u + .247u^2)\,10^{-5} \ldots\ldots\ldots (5)$$

These regression values of (a) were then substituted in Equation (1).

$$E_{p1} = (e_s - RHe_s)\,(2950u - 49.5u^2 + .235u^3)\,10\text{-}5 \ldots (6)$$

$$E_{p2} = (e_s - RHe_s)\,(3230u - 48.6u^2 + .234u^3)\,10^{-5} \ldots (7)$$

$$E_{p3} = (e_s - RHe_s)\,(3660u - 53.6u^2 + .247u^3)\,10^{-5} \ldots (8)$$

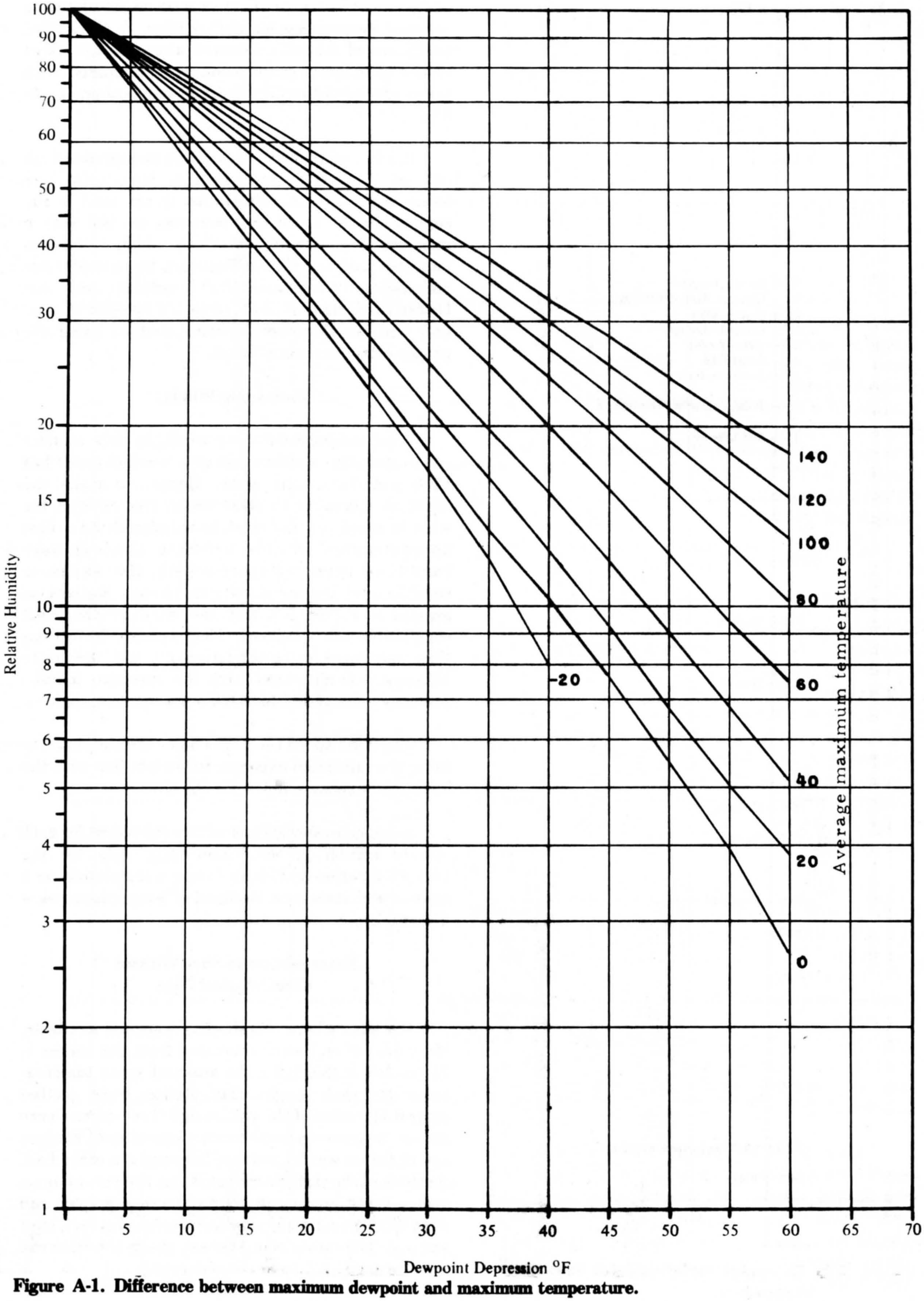

Figure A-1. Difference between maximum dewpoint and maximum temperature.

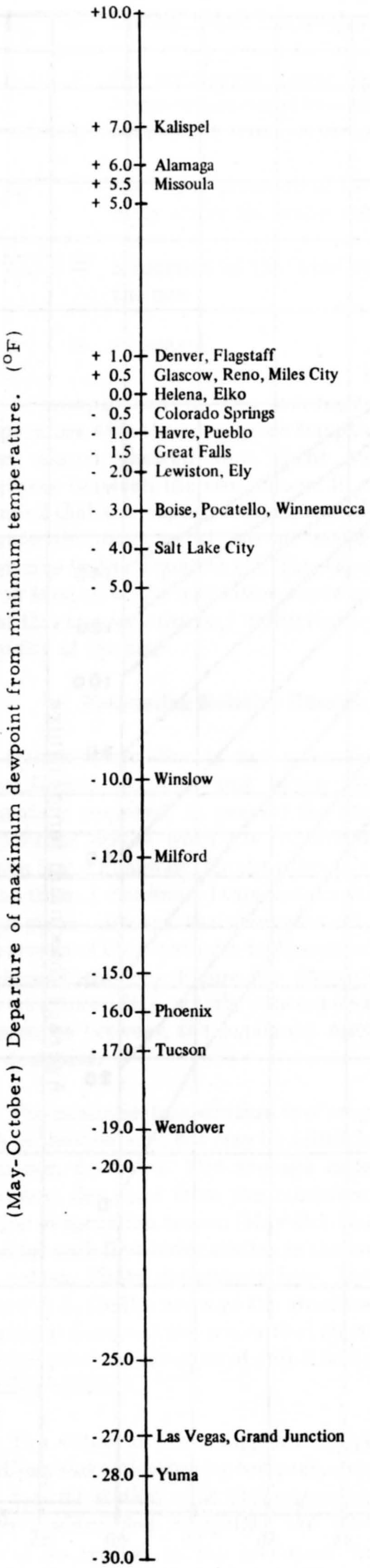

Figure A-2. Dewpoint variation from minimum temperature.

and these equations were then used to calculate the seasonal evaporation for each station. A correlation coefficient of .974 was obtained when the calculated values of seasonal evaporation were compared with the measured values. The average standard error was 3.04.

It is known that the evaporation measured at Fish Springs WLR is doubtful because birds drink and bathe in the pan. If this station is not used in the correlation the coefficient increases to .988 with a standard error of only 2.06. Such a high correlation indicates that the Dalton Equation has considerable potential for use under Utah conditions and that Dalton's "constant a" is essentially a function of wind only and can therefore be eliminated by using the proper cubic function of wind.

Estimating Winds

Wind measurements are available only at class (A) evaporation stations and at a few 2nd order and FFA stations in the state. Hence, to make the equation applicable to other areas, the value of the wind in miles per day must be estimated. As a first approximation of this estimate the exposure conditions were compared with the exposure conditions of the standard class A pan stations as arrayed in Figure A-4, and the wind at the most comparable site was used. The exposure factor was then calculated using Equation (2) and the value obtained was compared with the exposure indexes previously calculated for each evaporation station.

The wind speed estimates were then adjusted to bring the calculated exposure index into line with the estimated exposure index for the site.

Seasonal evaporation was then calculated for each climate station in the state using data for the 1941-1970 period and these values were plotted on a map of the state and iso-lines of evaporation were drawn.

Extrapolation to Sites Without Climatological Data

For sites where climate data were not available, the values of (e_s) were estimated from the curves in Figure A-5. In this figure the seasonal mean temperatures for each evaporation station were plotted against elevation of the station and three curves were drawn. Two curves made an envelope of most stations and the third was an average between the other two. Analysis of the stations revealed that the curves again grouped stations according to the topography and wind speed description used for determining (a_1), (a_2), and (a_3). The values of (e_s) for any site in the state can then be estimated from these curves.

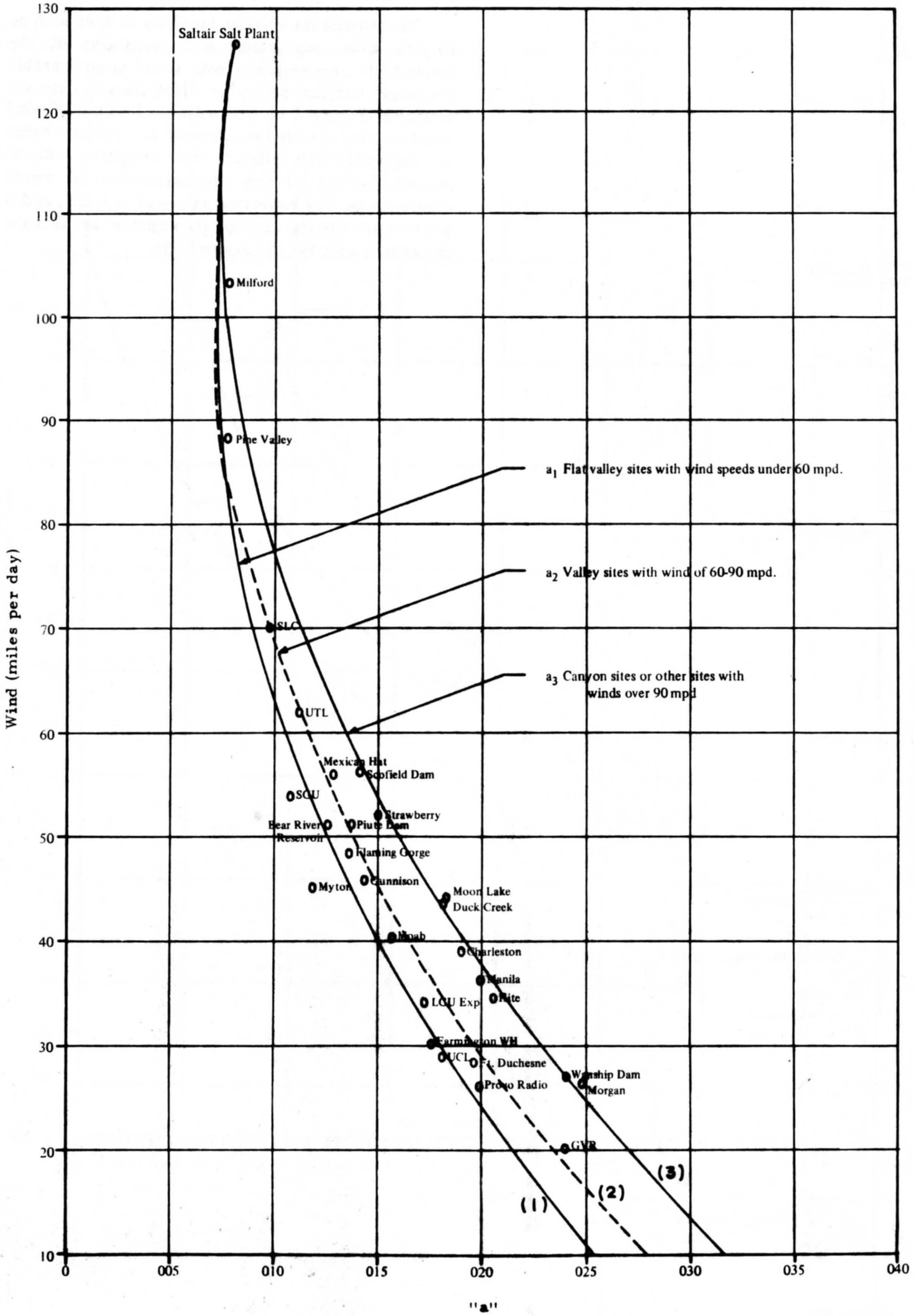

Figure A-3. Wind/"a" value correlation.

To estimate the relative humidity at sites with no climatic data, topography and vegetation at the desired site are compared with those at comparable previously estimated sites for which climatic data are available (Figure A-6). The estimated values of wind and humidity are used to calculate an exposure index for each site. This index is then compared with an estimated index for this site determined by visual observations. The estimated values of (e_s), RH, and u are then used in the appropriate equation to calculate the evaporation for the desired site.

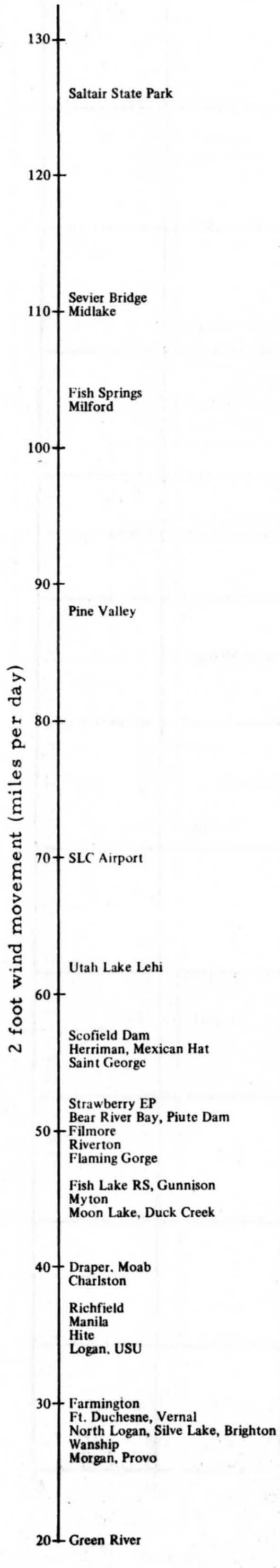

Figure A-4. May-October mean pan winds.

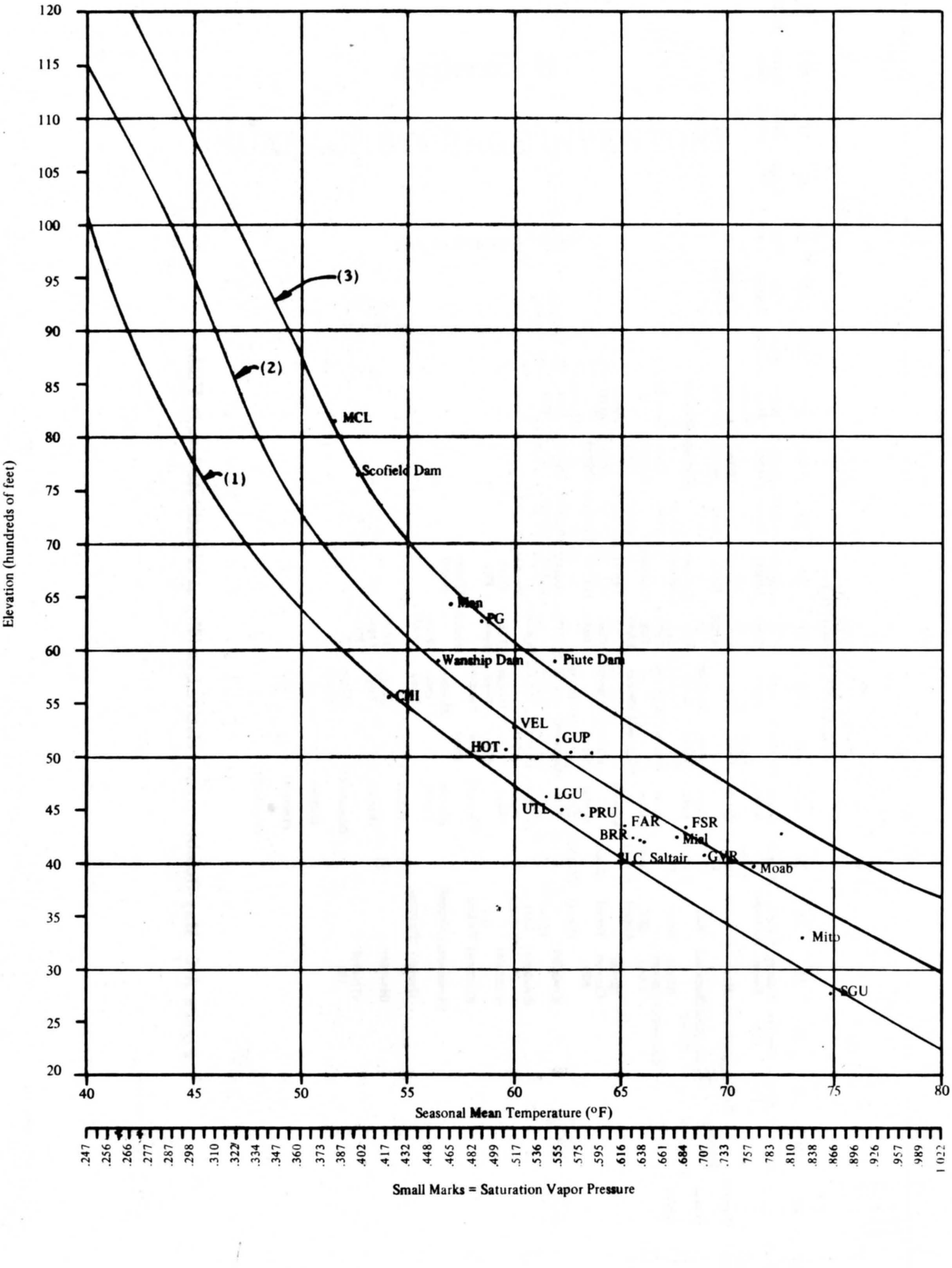

Figure A-5. Vapor pressure variation with elevation.

RELATIVE HUMIDITY

18	19	22	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	40	42	43	45	48	72
(Lund)	Milford (Black Rock)	(Modena) (Veyo) (ENV)	(Birdseye) (Bluff) (Ibapah) (Panguitch)	(Cove Fort) (Le Van)	Mexican Hat (Hardware) (Richfield Radio) (Snowville)	Flaming Gorge Moab (Bonanza) (Bryce Canyon FAA) (Bryce Canyon NP) (Coalville) (Escalante) (Fairfield) (Garrison) (Hovenweep) (Jensen) (Midvale) (Thiokol 78)	Fort Duchesne Gunnison Hite Myton SLC Airport Vernal (Cisco) (Clear Lake Refuge) (La Verkin) (Moroni) (Partoun)	Morgan Strawberry EP (Cedar PT) (Deer Creek) (Loa) (Nephi)	Green River Manila Moon Lake Piute Dam Wanship (Cedar City PH) (Cottonwood Weir) (Deseret) (Grouse Creek) (Heber) (Kanab) (Roosevelt) (Scipio) (Trenton) (Woodruff)	Charlston Duck Creek Pine Valley (Beaver) (Duchesne) (Echo Dam) (Lewiston) (Monticello) (Pine View Dam)	Farmington (Blanding) (Brigham City) (Corrine) (Delta) (Emery) (Fillmore) (Logan USU) (Logan Sugar Factory) (Mountain Dell Dam) (Oak City) (Ogden Sugar) (U of U)	Provo Radio Saint George (Alton) (Cedar City FAA) (Clear Creek) (Dugway) (Kamas) (Laketown) (Manti) (Richmond) (Snake Creek PH)	(Antelope Island) (Capitol Reef) (Ephriam Sorensons) (Garland) (HVE) (La Sal) (Logan Radio) (Pleasant Creek PH) (Thompsons)	Scofield Dam Utah Lake Lehi (Logan 5SW) (New Harmony) (Parawan) (Pleasant Grove) (Tooele)	Logan USU (Altamont) (Garfield) (Glen Canyon City) (Park Valley) (Price)	Bear River Refuge (ASSR) (Elberta) (Riverdale PH) (Santaquin) (Spanish Fork PH) (Zion)	(Park City)	Fish Springs (Bingham Canyon)	(Timp Cave)	Saltair SP	(Hiawatha)	(Lakeside)	Midlake

Figure A-6. May-October mean relative humidity at climatic stations in Utah.

Appendix B

SURFACE STORAGE INVENTORY

Key to Storage "Type"

Type Number	
0	SALT WATER
	FRESH WATER
	Natural Lake:
1	over 1,000 acres
2	100 to 1,000 acres
3	under 100 acres
4	unmanaged wetland (any size)
	Man-made (or natural but regulated):
5	over 1,000 acres
6	100 to 1,000 acres
7	under 100 acres
	Managed Wetlands:
8	Federal
9	State
10	Private

NO.	NAME	TYPE	BASIN	ELEV	MAXIMUM AREA (ACRES)	EFFECTIVE AREA (ACRES)	CAPACITY (AC FT)
1	GREAT SALT LAKE	0	1-6	4202	1560000	1150000	31400000
2	BLUE CREEK RESERVOIR	6	1-7	4600	166	108	2840
3	ROSE RESERVOIR	6	1-1	4425	235	0	1946
4	NEWTON RESERVOIR	6	2-2	4800	302	242	5374
5	'STRAIGHT FORK'	3	1-1	5400	30	30	
7	LOCOMOTIVE SPRINGS	9	1-1	4200	1150	1150	
9	'PENROSE'	3	2-1	4250	90	90	
10	'MUDDY CREEK RESERVOIR'	7	1-1	4700	50	33	
11	SINKS OF DOVE CREEK	3	1-1	4600	40	40	
12	COYOTE POND	3	1-7	4360	20	20	
13	PUBLIC SHOOTING GROUND	9	2-1	4235	2250	2250	
14	SALT CREEK	9	2-1	4250	295	295	
16	BEAR RIVER BIRD REFUGE	8	2-1	4200	20933	20933	
20	NORTH LAKE	4	2-1	4300	170	170	
21	'WEST NORTH LAKE'	4	2-1	4300	90	90	
24	BEAR RIVER WETLANDS	4	2-1	4210	1152	1152	
25	WILLARD RESERVOIR	5	2-1	4210	9950	9900	224880
26	WEBER RIVER WETLANDS	4	3-1	4210	315	315	
28	OGDEN BAY REFUGE	9	3-1	4200	3998	3998	
32	CUTLER RESERVOIR	5	2-2	4230	6000	6000	18690
33	BEAR LAKE	5	2-3	5925	70500	70000	6047200
34	SOUTH LAKE	3	2-3	6500	75	75	
35	NORTH LAKE	3	2-3	6700	30	30	
36	MANTUA RESERVOIR	6	2-2	5100	554	443	7560
37	'MENDON'	4	2-2	4435	40	40	
38	LITTLE CREEK RESERVOIR	7	2-3	6410	90	90	908
39	'RANDOLPH CREEK'	4	2-3	6200	75	75	
40	HYRUM RESERVOIR	6	2-2	4885	480	434	18623
41	DRY HOLLOW RESERVOIR	7	2-3	6400	40	26	
42	CAUSEY RESERVOIR	6	3-2	5690	136	122	7870
43	NEPONSET	5	2-3	6500	1043	678	8700
44	PORCUPINE RESERVOIR	6	2-2	5800	188	169	12800
45	PINEVIEW RESERVOIR	5	3-2	4900	2870	2626	110150
46	LOST CREEK RESERVOIR	6	3-2	6005	365	330	22150
47	'DUCK CREEK'	3	2-3	6900	75	75	
48	COBBLE CREEK	6	3-2	5400	530	477	37000
50	JORDAN RIVER WETLANDS	9	4-2	4200	1531	1531	
51	STOOKEY RESERVOIR	6	1-5	5000	200	200	500
52	TIMPIE SPRINGS	9	1-4	4200	640	640	
53	EAST CANYON RESERVOIR	6	3-2	5660	684	552	52000
54	ECHO RESERVOIR	5	3-2	5610	1470	1254	73940
55	JOYCE LAKE	6	3-2	9500	100	90	1600
57	LYMAN LAKE	3	7-1	9800	40	40	420
58	CHINAMEN LAKE	3	7-1	9400	35	35	
59	HOOP LAKE	7	7-1	8800	70	56	3925
60	BEAVER MEADOW	7	7-1	9500	70	56	1785
61	'REDWOOD'	4	4-2	4245	150	150	
62	DECKER RESERVOIR	6	4-2	4245	150	98	250
63	MOUNTAIN DELL RESERVOIR	6	4-2	5500	120	108	3514
64	ROCKPORT LAKE	5	3-2	6000	1080	991	62100
65	SARGENT LAKES	3	3-2	6700	30	30	
66	WASHINGTON LAKE	6	3-2	10000	100	100	3309
67	SMITH AND MOREHOUSE RES.	7	3-2	7600	44	30	423
68	'BALD MOUNTAIN'	3	3-2	9800	50	50	
69	FISH LAKE	7	3-2	9600	83	83	1142
70	MIRROR LAKE	3	7-3	9800	75	75	800
71	MEADOW LAKE	3	3-2	9900	34	34	
72	MCPHETERS LAKE	3	2-1	9800	80	80	
73	BLUEBELL LAKE	7	7-3	10000	42	34	235
74	FIVE POINT LAKE	7	7-3	10000	85	68	810
75	SUPERIOR LAKE	3	7-3	10200	47	38	320
76	RED CASTLE	2	7-1	11400	165	132	2900
77	WHITNEY	6	2-1	9400	150	135	4700
78	LAKE BLANCHARD	3	7-1	10800	75	75	
79	'RED CASTLE PEAK'	3	7-1	11600	75	75	
80	LAKE ATWOOD	6	7-3	11000	208	166	2700
81	CHAIN LAKES	3	7-3	10800	60	48	830

NO.	NAME	TYPE	BASIN	ELEV	MAXIMUM AREA (ACRES)	EFFECTIVE AREA (ACRES)	CAPACITY (AC FT)
82	ISLAND LAKE	2	7-1	9800	120	96	2500
83	TAMARACK LAKE	3	7-1	9800	50	40	670
84	FOX LAKE	2	7-3	10800	102	60	1065
85	FISH LAKE	7	7-1	9800	27	22	
86	CHEPETA LAKE	6	7-3	10800	128	102	2530
87	QUEANT LAKE	3	7-3	10800	57	46	10000
88	'T.L. RANGE STATION'	3	4-4	10000	80	60	
89	RED CREEK	6	7-3	9400	140	112	5700
90	LOST LAKE	5	4-4	10000	1300	1040	
91	MOHAWK LAKE	3	7-3	10600	40	40	
92	GRANDADDY LAKE	2	7-3	10400	120	96	1500
93	PINE ISLAND	3	7-3	10400	50	50	
94	PINTO LAKE	2	7-3	9900	115	115	2725
95	KIDNEY LAKE	6	7-3	10400	207	166	4825
96	CLEMENTS LAKE	7	7-3	9600	60	48	1200
97	MOON LAKE	6	7-3	8200	775	620	35800
98	DEER CREEK RESERVOIR	5	4-4	5420	2680	2550	149700
99	FARNSWORTH RESERVOIR	6	7-3	7800	184	147	3570
100	MIDVIEW RESERVOIR	6	7-3	5300	400	320	5800
101	UTAH LAKE	5	4-3	4490	95900	80877	850200
102	COLUMBIA STEEL COMPANY	6	4-3	4500	315	205	4500
103	'PROVO'	4	4-3	4490	60	60	
104	THIRTY OAKS	2	4-4	5200	400	400	10000
105	STRAWBERRY RESERVOIR	5	7-3	7590	15420	12680	870000
106	LAKE BOREHAM	2	7-3	5300	100	100	
107	BIG SAND WASH	6	7-3	6000	393	196	12050
108	STARVATION	5	7-3	5800	3310	2648	167310
109	FLAMING GORGE RESERVOIR	5	7-1	6000	41800	27700	3788900
110	DAGGETT LAKE	3	7-1	10600	44	35	333
111	WHITEROCKS RESERVOIR	7	7-3	10600	70	56	918
112	JOHNSON LAKE	1	7-3	10400	1330	1064	5680
113	TWIN LAKES	7	7-2	10100	49	39	500
114	LONE PARK RESERVOIR	7	7-2	10000	63	50	520
115	OAKS PARKS RESERVOIR	6	7-2	9400	382	306	6730
116	EAST PARK RESERVOIR	6	7-2	9000	165	132	2650
117	CALDER POND	7	7-1	7600	98	78	452
118	CROUSE RESERVOIR	6	7-1	7160	135	109	1516
119	'GREEN RIVER'	4	7-1	5600	40	26	
120	TWIN LAKES RESERVOIR	6	7-2	5600	366	293	476
121	PARADISE PARK RESERVOIR	6	7-2	10000	143	114	2840
122	STEINAKER RESERVOIR	6	7-2	5600	820	656	38173
123	STUART LAKE	6	7-4	5000	304	243	1516
124	MONTEZ CREEK RESERVOIR	7	7-3	5320	89	45	1280
125	PELICAN LAKE	4	7-3	4800	1141	571	6750
127	GRANITE RESERVOIR	7	1-2	5000	76	49	186
128	GUNNISON BEND	6	5-2	4600	865	562	6400
129	SEVIER BRIDGE RESERVOIR	5	5-3	5015	10905	2950	236145
130	CARR LAKE	4	5-2	4500	40	26	
131	'VAN'	4	5-2	4600	60	39	
132	CLEAR LAKE	9	5-2	4600	1330	1330	
133	SCIPIO LAKE	5	5-2	6000	1400	300	9800
134	FOOL CREEK RESERVOIR NO. 1	6	5-2	4800	400	200	17781
135	FOOL CREEK RESERVOIR NO. 2	6	5-2	4800	652	326	5217
137	DMAD	5	5-2	4700	1198	599	10990
138	SUMMIT CREEK RESERVOIR	6	4-3	5000	109	71	
139	MONA RESERVOIR	5	4-2	5000	2395	1557	19000
140	LOWER GOOSEBERRY RES.	7	8-1	8400	40	32	300
141	SCOFIELD RESERVOIR	5	8-1	7590	2810	2520	65800
143	FISH SPRINGS	8	1-2	3800	7200	7200	
144	CHICKEN CREEK RESERVOIR	6	5-2	5100	490	323	2000
145	WALES RESERVOIR	6	5-1	5600	200	130	1480
146	ELECTRIC LAKE	6	8-2	8400	440	352	31000
147	HUNTINGTON RESERVOIR	6	8-2	9000	250	200	5910
148	MILLER FLAT	6	8-2	8900	160	128	5560
149	CLEVELAND RESERVOIR	6	8-2	9000	137	110	3275
150	ROLF SON RESERVOIR	7	8-2	9000	45	45	900
151	'WHITMORE'	3	8-1	7000	30	24	
152	TOPAZ SLOUGH	9	5-2	4500	830	830	
153	DESERT LAKE	9	8-1	5500	544	544	7300

NO.	NAME	TYPE	BASIN	ELEV	MAXIMUM AREA (ACRES)	EFFECTIVE AREA (ACRES)	CAPACITY (AC FT)
154	OLSEN RESERVOIR	7	8-1	5500	80	40	3500
155	GUNNISON RESERVOIR	5	5-1	5400	1420	1136	24118
156	FUNKS LAKE	2	5-1	6000	150	150	607
157	FERRUN RESERVOIR	7	8-2	9600	75	60	1400
158	NINE MILE RESERVOIR	6	5-3	5500	209	167	3537
159	BUCKHORN RESERVOIR	7	8-2	5900	75	38	4508
160	WILLOW CREEK RESERVOIR	7	5-3	5800	40	20	130
161	ISLAND LAKE	3	5-3	9600	43	34	640
162	MILLSITE	6	8-2	6400	435	348	18000
163	GRAND CANYON P.C.	5	8-5	4200	1771	1151	33000
164	TOWAVE RESERVOIR	7	7-4	6600	20	16	180
165	HERCULES RESERVOIR	7	9-1	4900	264	211	13000
166	COTTONWOOD RESERVOIR	5	9-1	4500	1125	731	24800
167	'CUDAHY'	3	6-1	5200	25	15	
168	DUTCHMAN RESERVOIR	7	5-8	4800	20	13	
169	NEWHOUSE RESERVOIR	7	5-8	4800	20	13	
170	THREE CREEKS RESERVOIR	7	5-4	6900	57	46	2030
171	'RANCH'	4	6-1	4920	20	13	
172	BIG WASH RESERVOIR	7	6-1	5800	80	56	97
173	BARNEY LAKE	7	5-4	9600	19	19	172
174	MINERSVILLE RESERVOIR	6	6-1	5600	950	760	25080
175	PUFFER LAKE	3	6-1	9800	75	60	897
176	PIUTE RESERVOIR	5	5-4	5995	2598	1480	71826
177	OTTER CREEK RESERVOIR	5	5-5	6350	2768	2200	63246
178	ROCKY FORD RESERVOIR	5	5-4	5400	1129	903	23260
179	REDMUND LAKE	4	5-3	5200	27	22	
180	SKUMOAH RESERVOIR	7	5-3	8000	30	24	
181	SHEEP VALLEY	7	8-3	8800	86	69	2314
182	KOOSHAREM RESERVOIR	6	5-5	7100	401	321	3858
183	JOHNSON VALLEY RESERVOIR	6	8-3	9000	762	610	14770
184	FISH LAKE	5	8-3	9000	3153	2522	
185	FORSYTH RESERVOIR	6	8-3	8000	171	137	3419
186	MILL MEADOW RESERVOIR	7	8-3	7800	94	75	5232
187	BOTTLE HOLLOW	4	7-3	4800	418	418	11100
188	THURBER RESERVOIR	5	8-3	7000	3254	2596	137525
189	'LOOKOUT PEAK'	3	8-3	11000	30	30	
190	'DONKEY MEADOWS'	3	8-3	9800	30	30	
191	DONKEY RESERVOIR	3	8-3	9900	40	32	500
192	JACOBS RESERVOIR	6	8-4	10000	359	288	1967
193	MCGATH LAKE	3	8-4	9600	60	48	1100
194	'EAST MCGATH'	3	8-4	9600	30	30	
195	SPECTACLE LAKE RESERVOIR	7	8-4	10900	250	200	1429
196	GRASS LAKE	3	8-4	9800	30	30	
197	OAK CREEK RESERVOIR	3	8-3	10000	40	32	1000
198	DEER CREEK LAKE	3	8-4	10000	81	64	800
199	BOWNS RESERVOIR	7	8-3	6400	30	30	
200	VALLEY CITY RESERVOIR	7	8-5	4800	80	40	457
201	HOOSIER LAKE	6	6-2	8600	159	159	1086
202	PARAGONAH RESERVOIR	6	6-2	5800	132	85	1733
203	RED CREEK RESERVOIR	7	6-2	7800	50	40	
204	YANKEE MEADOWS RESERVOIR	7	6-2	8800	60	48	
205	QUICHAPA LAKE	2	6-3	5600	777	622	5290
206	PANGUITCH LAKE	5	5-6	8400	1548	1238	54670
207	ROUNDY RESERVOIR	6	5-6	7800	117	94	970
208	'BLUE SPRING'	7	5-6	9600	24	19	255
209	LOWER ENTERPRISE RESERVOIR	7	6-3	5800	75	49	2423
210	ENTERPRISE RESERVOIR	6	6-3	5800	335	268	8500
211	KOLOB RESERVOIR	6	10-1	8095	250	200	5586
212	MAMMOTH CREEK RES.	6	5-6	7600	614	491	14509
213	NAVAJO LAKE	6	5-6	9000	728	582	14869
214	TROPIC LAKE RESERVOIR	6	5-5	8000	200	120	1750
215	UPPER SAND COVE RES.	7	10-1	4400	30	20	
216	GRASS VALLEY CREEK	6	10-1	9000	975	780	26650
217	BAKER DAM RESERVOIR	7	10-1	5000	51	41	1160
218	ASH CREEK RESERVOIR	6	10-1	4830	297	193	9928
219	LE VANGEN LAKES	3	10-1	7000	30	30	
220	'S.C. BENCH'	4	10-1	3200	30	30	
221	CYCLONE LAKE	3	8-4	10000	30	30	
222	PINE LAKE	3	5-5	7800	83	66	

NO.	NAME	TYPE	BASIN	ELEV	MAXIMUM AREA (ACRES)	EFFECTIVE AREA (ACRES)	CAPACITY (AC FT)
223	LAKEVIEW	7	6-4	8800	30	24	537
224	WIDE HOLLOW RESERVOIR	6	8-4	6000	146	96	2325
225	LAKE POWELL	5	9-4	3700	162700	114000	27162000
226	DUCK LAKE	6	9-3	7400	728	582	14216
227	BLUE MOUNTAIN	6	9-1	6900	204	163	1200
228	JONES RESERVOIR	6	9-1	7000	163	130	1435
230	JOE.S VALLEY RESERVOIR	5	8-2	7000	1170	867	62500
231	DOG VALLEY	6	5-6	7500	362	288	1046
232	PRUESS	6	1-3	5400	250	200	5800
233	BIG LAKE	6	5-5	8600	126	113	1060
235	FARMINGTON BAY	9	4-2	4204	3161	3161	
236	HOWARD SLOUGH	9	3-1	4204	2300	2300	
237	RAINBOW CLUB	10	3-1	4204	192	192	
238	SAGEBRUSH CLUB	10	2-1	4204	203	203	
239	DUCKVILLE CLUB	10	2-1	4204	90	90	
240	CHESAPEAKE CLUB	10	2-1	4204	565	565	
241	BEAR RIVER CLUB	10	2-1	4204	5469	5469	
242	NORTH PT. FUR CLUB	10	4-2	4204	136	136	
243	LAKE FRONT CLUB	10	4-2	4204	57	57	
244	RUDY CLUB	10	4-2	4204	565	565	
245	HARRISON CLUB	10	4-2	4204	328	328	
246	UTAH CLUB	10	4-2	4204	34	34	
247	GUNLOCK RESERVOIR	6	10-1	3600	266	208	10884

Appendix C

MONTHLY AIRPORT WIND DATA

ELY

Form of Data:
Microfiche

Height of Anemometer = 47'
Data Frequency = 1 hr.

% Time over 5 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	57.8	49.4	57.8	54.8	59.6	56.0	55.9
1971	55.0	52.5	51.3	49.5	63.1	59.7	55.18
1972	55.9	54.6	57.0	63.6	56.2	-	-
	56.23	52.17	55.37	55.97	59.63	57.85	56.19

% Time over 10 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	7.3	8.9	4.8	4.6	6.7	5.2	6.25
1971	10.6	6.4	4.0	2.3	10.8	10.2	7.38
1972	7.5	8.1	4.4	4.8	7.5	-	-
	8.47	7.8	4.4	3.9	8.33	7.7	6.73

% Time over 15 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	.3	1.0	.6	0	.8	0	.45
1971	1.3	0	.1	.1	1.2	1.2	.65
1972	.4	.8	.5	.4	.1	-	-
	.67	.6	.4	.17	.7	.6	.52

Average wind at 2 meters (mph)

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	5.5	5.25	5.36	5.06	5.53	5.33	5.35
1971	5.35	5.14	4.94	4.96	5.95	5.72	5.34
1972	5.39	5.52	5.27	5.55	5.31	-	-
	5.44	5.30	5.19	5.19	5.60	5.52	5.37

May-Oct. Means at 47' = 8.5 KPH
at 2 meters = 5.37 MPH
at 2 Ft. = 3.76 MPH

HILL FIELD SUMMARY

Form of Data:
Air Force Summary*

Height of Anemometer = 15'
Data Frequency = 1 hr.

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
% over 5 mph	58	56	40	56.5	50	50	51.7
% over 10 mph	17	17	17.6	18	16	14.6	16.7
% over 15 mph	4	4	3.5	4	4.4	4	4.0
Avg. 2m. wind	7.9	7.9	8.0	8.2	7.6	7.4	7.8

*The previously developed summary was based upon data for the period 1941 to 1965.

May-Oct Means at 15' = 8.58 KPH
at 2 meters = 7.8 MPH
at 2 Ft. = 5.46 MPH

WENDOVER

Form of Data:
Air Force Summary*

Height of Anemometer =22, 31, 60'
Data Frequency = 1 hr.

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
% over 5 mph	26	26	20	17	26	13	21.3
% over 10 mph	4	3.8	2.3	2.5	4	1.8	3.1
% over 15 mph	0.7	0.7	0.4	0.4	0.7	0.3	0.5
Avg. 2m. wind	4.5	4.4	4	3.9	3.4	3	3.9

*The previously developed summary was based upon data for the period: Aug. 1942-Feb. 1946, June 1946-May 1947, July 1947-Nov. 1949, March 1950-Dec. 1954, Nov. 1956-Oct. 1957, Sept. 1959-Dec. 1965.

May-Oct Means at 22, 31, 60' = 5.65 KPH
at 2 meters = 3.9 MPH
at 2 Ft. = 2.73 MPH

SALT LAKE (NEW)

Form of Data:
Microfiche

Height of Anemometer = 20'
Data Frequency = 1 hr.

% Time over 5 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	74.0	77.5	79.0	74.6	74.0	72.3	75.23
1971	72.6	76.9	73.2	80.2	77.8	74.6	75.88
1972	-	75.8	79.3	80.8	75.4	73.1	
	73.30	76.73	77.17	78.53	75.73	73.33	75.9

% Time over 10 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	15	13.7	15.4	14.5	15	13.2	14.47
1971	15.6	16.5	15.2	21.1	24.8	17.3	18.42
1972	-	24.7	16.0	17.1	18.5	16.7	-
	15.3	18.3	15.53	17.57	19.43	15.73	16.98

% Time over 15 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	2.3	2.5	1.5	1.1	3.6	2.5	2.25
1971	2.5	2.8	1.2	1.9	7.2	2.5	3.02
1972	-	5.4	2.0	2.8	6.0	2.4	-
	2.4	3.57	1.57	1.93	5.6	2.47	2.92

Average wind at 2 meters (mph)

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1970	6.2	6.12	6.2	6.04	6.2	5.89	6.11
1971	6.12	6.35	6.12	6.27	7.11	6.12	6.35
1972	-	6.88	6.35	6.58	6.66	6.12	-
	6.16	6.45	6.22	6.30	6.66	6.04	6.33

May-Oct Means at 20' = 8.27 KPH
at 2 meters = 6.33 MPH
at 2 ft. = 4.43 MPH

SALT LAKE AIRPORT (ORIGINAL)

Form of Data:
Weather Bureau Summary*

Height of Anamometer = 23'-58'**
Data Frequency = 1 hr.

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
% over 5 mph	29.8	31.3	27.5	35.3	24.8	20.7	28.2
% over 10 mph	3.5	4.0	2.5	3.9	2.3	2.0	3.0
% over 15 mph	0.5	.1	.1	.1	.1	0	.1
Avg. 2m. wind	5.3	5.4	5.2	5.6	5.0	4.7	5.2

*The previously developed summary was based upon 1951 to 1960 data.

**The instrument was at the following heights:

Height	Period
58'	1948 to July 1954
33'	July 1954 to Sept. 1959
20'	Sept. 1959 to present

A weighted factor was used to reduce winds to 2 meters.

GREEN RIVER

Form of Data:
Microfilm

Height of Anemometer = 26'
Data Frequency = 6 hr.

% Time over 5 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1961	17.7	6.7	5.6	.8	5.8	5.6	7.0
1963	29.0	35.8	25.8	18.5	7.5	7.2	20.6
1964	32.2	25.8	19.3	17.7	20.0	7.2	20.4
1965	37.9	20.8	16.9	4.0	20.8	2.4	17.1
1966	24.4	20.8	12.1	16.1	10.8	6.4	14.9
1967	25.8	23.3	13.7	15.3	11.7	16.9	17.8
1968	25.8	25.8	16.1	15.3	15.0	10.5	18.1
1969	16.9	22.5	12.1	12.9	7.5	13.7	14.3
1970	29.8	22.5	18.5	8.9	21.7	12.9	19.0
1971	28.2	18.3	15.3	8.9	19.2	17.7	17.9
	26.65	22.25	15.5	11.85	14.0	10.0	16.71

% Time over 10 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1961	3.2	.8	.8	.0	1.7	1.6	1.35
1963	8.0	13.3	3.2	2.4	2.5	1.6	5.16
1964	12.1	8.4	4.0	3.2	5.0	.8	5.58
1965	12.1	2.5	5.6	.8	4.2	.8	4.33
1966	6.4	3.3	3.2	4.8	3.3	1.6	3.76
1967	6.4	5.0	0.8	1.6	0	5.6	3.2
1968	2.4	5.8	2.4	2.4	5.0	1.6	3.3
1969	1.6	3.2	0	2.4	0.8	1.6	1.7
1970	5.6	2.5	0	1.6	5.0	0.8	2.6
1971	5.6	3.3	0.8	0	3.3	3.2	2.7
	6.33	4.83	2.08	1.92	3.07	1.94	3.36

GREEN RIVER (continued)

% Time over 15 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1961	1.6	0	.8	0	0	0	.4
1963	1.6	3.3	0	0	.8	0	.95
1964	.8	1.7	0	1.6	1.7	0	.96
1965	3.2	0	.8	0	0	.8	.8
1966	0	.8	1.6	0	.8	0	.53
1967	.8	.8	0	0	0	1.6	.5
1968	.8	0	0	0	0	0	.1
1969	0	1.6	0	0	0	0	.3
1970	.8	0	0	0	.8	.8	.4
1971	0	0	.8	0	0	0	.1
	.97	.83	.47	.16	.48	.33	.54

Average wind at 2 meters (mph)

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1969	3.5	3.22	3.02	2.89	2.59	2.85	3.01
1970	4.22	3.52	2.95	2.79	3.48	2.81	3.29
1971	4.17	3.43	3.15	2.61	3.24	2.90	3.25
	3.96	3.39	3.04	2.76	3.10	2.85	3.18

May-Oct Means at 26' = 4.13 KPH
at 2 meters = 3.18 MPH
at 2 Ft. = 2.23 MPH

CEDAR CITY

Form of Data: Microfilm

Height of Anemometer = 42'
Data Frequency = 1 hr.

% Time over 5 mph at 6.5'

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	50.4	50.4	36.3	32.4	32.6	42.6	40.8
1968	49.6	49.6	41.0	44.2	45.0	32.5	43.6
1970	49.6	51.0	35.1	29.0	38.2	44.1	41.2
	49.9	50.3	37.5	35.2	38.6	39.7	41.9

% Time over 10 mph at 6.5'

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	12.5	10.9	3	4	5	8.7	7.35
1968	11.2	10.2	4.4	11.2	7.8	6	8.5
1969	8.5	10.2	4.3	2	3	4.3	5.38
1970	7.5	18.8	5.7	2	11.4	12.1	9.58
1971	15.5	14	11	4.7	18.4	14.4	13.0
	11.0	12.8	5.7	4.8	9.1	9.1	8.76

% Time over 15 mph

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	1	1	0	0	0	<1	0
1968	1	1	<1	1	1	0	1
1969	<1	2	<1	0	0	<1	1
1970	<1	2	<1	0	2	1	1
1971	3	<1	0	<1	4	2	2
	1.4	1.4	0.6	.4	1.4	1	1.0

CEDAR CITY (continued)

Average wind at 2 meters (mph)

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	5.2	5.2	4.4	4.3	4.3	4.9	4.7
1968	5.1	5.2	4.6	4.9	4.9	4.0	4.8
1969	4.9	4.5	4.2	4.1	3.9	3.9	4.3
	5.1	5.0	4.4	4.4	4.3	4.3	4.6

May-Oct Means at 26' = 7.0 KPH
at 2 meters = 4.6 MPH
at 2 Ft. = 3.22 MPH

BULL FROG BASIN WIND SUMMARY

Form of Data
Summary by State Climatologist*

Height of Anemometer = 22'
Data Frequency = 6 hr.

% Time over 5 mph at 2 meters

May	June	July	Aug.	Sept.	Oct.	Average
50.8	54.2	38.8	27.8	41.7	32.9	41.03%

% Time over 10 mph at 2 meters

May	June	July	Aug.	Sept.	Oct.	Average
21.0	14.0	10.7	8.9	18.3	12.0	14.15%

% Time over 15 mph at 2 meters

May	June	July	Aug.	Sept.	Oct.	Average
8.0	4.0	2.7	2.0	5.2	4.0	4.32%

Average wind at 2 meters (mph)

May	June	July	Aug.	Sept.	Oct.	Average
6.33	6.09	5.53	4.90	5.95	5.18	5.67

*The previously developed summary was based upon data from July 1970 to Dec. 1973.

May-Oct. Means at 25 ft. = 8.1 MPH
at 2 meters = 5.67 MPH
at 2 ft. = 3.96 MPH

BRYCE CANYON

Form of Data:
Previous Summary by
State Climatologist

Height of Anemometer = 38'
Data Frequency = 1 hr.

% Time over 5 mph at 6.5'

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	55.5	53.7	38.2	31.0	35.8	48.9	43.8
1968	47.3	50.4	34.3	36.2	47.5	39.9	42.6
1969	48.3	41.4	34.0	31.2	33.6	44.2	38.9
	50.4	48.5	35.5	32.8	39.0	44.3	41.7

% Time over 10 mph at 6.5'

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	7.1	8.3	1.2	1.5	3.3	7.1	4.7
1968	9.4	6.8	2.1	6.6	7.2	4.8	6.1
1969	10.6	5.0	3.8	1.2	2.2	5.6	4.7
	9.0	6.7	2.4	3.1	4.2	5.8	5.2

% Time over 15 mph

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1967	-	-	-	-	-	<1	1
1968	-	-	-	-	<1	-	1
1969	-	-	-	-	-	-	0

Average wind at 2 meters (mph)

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1968	5.14	5.25	4.18	4.40	5.13	4.57	4.78
1969	5.15	4.65	3.98	3.86	4.0	4.70	4.41
	5.15	4.96	4.09	4.1	4.56	4.61	4.59

May-Oct Mean at 38' = 6.77 KPH
at 2 meters = 4.59 MPH
at 2 Ft. = 3.21 MPH

HANKSVILLE

Form of Data:
Microfilm

Height of Anemometer = 25'
Data Frequency = 1 hr.

% Time over 5 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct
1963	47.2	56.2	39.2	33.1	21.0	20.8	36.2
1964	53.0	48.3	48.5	44.6	36.8	21.5	42.1
1965	56.6	48.7	43.0	39.7	45.6	14.1	41.3
	52.3	51.1	43.7	39.1	34.5	18.8	39.9

% Time over 10 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1963	17.2	23.7	8.2	7.1	5.0	6.2	11.2
1964	24.8	20.4	12.6	15.6	14.0	4.2	15.3
1965	27.9	20.5	12.7	5.9	18.7	2.3	14.7
	23.3	21.6	11.2	9.5	12.6	4.2	13.7

% Time over 15 mph at 2 meters

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1963	4.8	5.8	.3	1.9	.3	.8	2.3
1964	7.8	4.2	2.4	3.6	2.2	.7	3.5
1965	10.2	5.5	2.2	.8	6.2	.7	4.3
	7.6	5.2	1.63	2.1	2.9	.7	3.35

Average wind at 2 meters (mph)

	May	June	July	Aug.	Sept.	Oct.	May-Oct.
1963	5.25	6.09	4.13	3.68	2.72	2.62	4.08
1964	6.5	6.31	5.48	5.2	4.53	2.64	5.11
1965	6.22	5.47	4.84	4.06	5.33	2.19	4.68
	5.99	5.95	4.81	4.31	4.19	2.48	4.62

May-Oct. Means at 25 ft. = 6.0 KPH
at 2 meter = 4.62 MPH
at 2 ft. = 3.23 MPH

Appendix D

SURFACE STORAGE EVAPORATION AND SUPPRESSION ESTIMATES

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION ANNUAL (INCHES)	LAKE EVAPORATION SEASONAL (INCHES)	LAKE EVAPORATION SEASONAL (AC FT)	MONOLAYER MODEL SITE FACTOR	MONOLAYER MODEL PERCENT SUPPRESSION	MONOLAYER MODEL SALVAGE (AC FT)
1	GREAT SALT LAKE	4202	1150000	4.4			37.7	3600000			
2	BLUE CREEK RESERVOIR	4600	108	4.4	50	45	36	324	5	22	71
3	ROSE RESERVOIR	4425	0	4.2	48	43	34	0	3	80	0
4	NEWTON RESERVOIR	4800	242	4.4	42	37	30	601	6	24	144
5	'STRAIGHT FORK'	5400	30	3.9	44	40	32	79	6	12	10
7	LOCOMOTIVE SPRINGS	4200	1150	7.0	59	52	42	4014	3	10	401
9	'PENROSE'	4250	90	4.4	49	43	35	261	2	10	26
10	'MUDDY CREEK RESERVOIR'	4700	33	5.3	49	43	35	96	2	5	5
11	SINKS OF DOVE CREEK	4600	40	5.3	49	43	35	116	1	4	5
12	COYOTE POND	4380	20	7.0	59	52	42	70	4	6	4
13	PUBLIC SHOOTING GROUND	4235	2250	4.4	47	42	33	6257	5	22	1377
14	SALT CREEK	4250	295	4.4	49	43	35	855	4	19	162
16	BEAR RIVER BIRD REFUGE	4200	20933	4.5	47	42	33	58211	6	18	10478
20	NORTH LAKE	4300	170	4.0	52	46	37	523	3	17	89
21	'WEST NORTH LAKE'	4300	90	4.0	52	46	37	277	3	12	33
24	BEAR RIVER WETLANDS	4210	1152	4.4	46	41	33	3135	7	26	815
25	WILLARD RESERVOIR	4210	9900	4.4	48	43	34	28116	4	19	5342
26	WEBER RIVER WETLANDS	4210	315	4.4	48	43	34	895	7	26	233
28	OGDEN BAY REFUGE	4200	3998	4.4	48	42	34	11194	4	19	2127
32	CUTLER RESERVOIR	4230	6000	3.1	40	36	28	14200	5	27	3834
33	BEAR LAKE	5925	70000	3.4	40	36	28	165667	4	11	18223
34	SOUTH LAKE	6500	75	3.1	34	30	24	151	5	20	30
35	NORTH LAKE	6700	30	3.1	32	28	23	57	5	13	7
36	MANTUA RESERVOIR	5100	443	3.2	37	33	26	970	4	24	233
37	'MENDON'	4435	40	3.1	40	36	28	95	3	11	10
38	LITTLE CREEK RESERVOIR	6410	90	3.9	36	32	26	192	3	12	23

						LAKE EVAPORATION				MONOLAYER MODEL	
NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	SITE FACTOR	PERCENT SUPPRESSION	SALVAGE (AC FT)
39	'RANDOLPH CREEK'	6200	75	3.5	36	32	26	160	3	14	22
40	HYRUM RESERVOIR	4885	434	4.0	43	38	31	1104	7	27	298
41	DRY HOLLOW RESERVOIR	6400	26	3.7	38	34	27	58	2	8	5
42	CAUSEY RESERVOIR	5690	122	3.9	50	44	36	361	5	22	79
43	NEPONSET	6500	678	3.9	31	28	22	1244	4	20	249
44	PORCUPINE RESERVOIR	5800	169	4.8	46	41	33	460	4	17	78
45	PINEVIEW RESERVOIR	4900	2626	3.5	52	46	37	8079	5	24	1939
46	LOST CREEK RESERVOIR	6005	330	4.8	48	43	34	937	5	19	178
47	'DUCK CREEK'	6900	75	3.9	30	27	21	133	4	15	20
48	COBBLE CREEK	5400	477	3.8	46	41	33	1298	6	24	312
50	JORDAN RIVER WETLANDS	4200	1531	6.1	57	50	40	5091	7	21	1069
51	STOOKEY RESERVOIR	5000	200	5.3	52	46	36	607	3	14	85
52	TIMPIE SPRINGS	4200	640	3.5	57	50	40	2128	5	24	511
53	EAST CANYON RESERVOIR	5660	552	3.1	50	44	36	1633	5	27	441
54	ECHO RESERVOIR	5610	1254	2.5	41	36	29	2999	4	28	840
55	JOYCE LAKE	9500	90	3.5	18	16	13	95	5	18	17
57	LYMAN LAKE	9800	40	4.0	19	17	13	44	5	11	5
58	CHINAMEN LAKE	9400	35	4.0	20	18	14	41	5	11	4
59	HOOP LAKE	8800	56	3.5	21	18	15	69	5	18	12
60	BEAVER MEADOW	9500	56	4.0	20	18	14	65	5	16	10
61	'REDWOOD'	4245	150	6.1	57	50	40	499	3	13	65
62	DECKER RESERVOIR	4245	98	6.1	57	50	40	326	4	12	39
63	MOUNTAIN DELL RESERVOIR	5500	108	2.6	44	39	31	277	5	30	83
64	ROCKPORT LAKE	6000	991	2.5	38	33	27	2197	4	28	615
65	SARGENT LAKES	6700	30	3.7	28	25	20	49	5	12	6
66	WASHINGTON LAKE	10000	100	3.9	20	18	14	117	5	22	26

						LAKE EVAPORATION			MONOLAYER MODEL		
NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	SITE FACTOR	PERCENT SUPPRESSION	SALVAGE (AC FT)
67	SMITH AND MOREHOUSE RES.	7600	30	4.2	24	21	17	42	5	11	5
68	'BALD MOUNTAIN'	9800	50	4.2	20	18	14	58	5	16	9
69	FISH LAKE	9600	83	4.2	20	18	14	97	5	16	15
70	MIRROR LAKE	9800	75	4.2	20	18	14	88	5	16	14
71	MEADOW LAKE	9900	34	4.2	20	18	14	40	5	11	4
72	MCPHETERS LAKE	9800	80	4.2	20	18	14	93	5	16	15
73	BLUEBELL LAKE	10000	34	3.9	18	16	13	36	5	11	4
74	FIVE POINT LAKE	10000	68	3.9	18	16	13	71	5	16	11
75	SUPERIOR LAKE	10200	38	3.9	17	15	12	38	5	11	4
76	RED CASTLE	11400	132	3.9	16	14	11	123	5	22	27
77	WHITNEY	9400	135	4.0	19	17	13	150	5	22	33
78	LAKE BLANCHARD	10800	75	3.5	18	16	13	79	5	18	14
79	'RED CASTLE PEAK'	11600	75	3.2	15	13	11	66	5	20	13
80	LAKE ATWOOD	11000	166	3.7	15	13	11	145	5	24	35
81	CHAIN LAKES	10800	48	3.5	16	14	11	45	5	12	5
82	ISLAND LAKE	9800	96	3.2	17	15	12	95	5	20	19
83	TAMARACK LAKE	9800	40	3.5	18	16	13	42	5	12	5
84	FOX LAKE	10800	80	3.3	15	13	11	70	5	18	13
85	FISH LAKE	9800	22	3.2	17	15	12	22	5	13	3
86	CHEPETA LAKE	10800	102	3.5	15	13	11	89	5	24	21
87	QUEANT LAKE	10800	46	3.5	15	13	11	40	5	12	5
88	'T.L. RANGE STATION'	10000	80	4.2	20	18	14	93	5	16	15
89	RED CREEK	9400	112	3.2	18	16	13	118	5	27	32
90	LOST LAKE	10000	1040	4.2	20	18	14	1213	5	22	267
91	MOHAWK LAKE	10600	40	3.3	16	14	11	37	5	12	4
92	GRANDADDY LAKE	10400	96	3.3	17	15	12	95	5	16	17

						LAKE EVAPORATION			MONOLAYER MODEL		
NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	SITE FACTOR	PERCENT SUPPRESSION	SALVAGE (AC FT)
93	PINE ISLAND	10400	50	3.3	17	15	12	50	5	18	9
94	PINTO LAKE	9900	115	3.3	17	15	12	114	5	24	27
95	KIDNEY LAKE	10400	166	3.3	17	15	12	165	5	24	40
96	CLEMENTS LAKE	9600	48	3.5	18	16	13	50	5	12	6
97	MOON LAKE	8200	620	4.0	27	24	19	977	7	27	264
98	DEER CREEK RESERVOIR	5420	2550	3.5	48	42	34	7140	5	24	1714
99	FARNSWORTH RESERVOIR	7800	147	3.9	26	23	18	223	5	22	49
100	MIDVIEW RESERVOIR	5300	320	3.1	34	29	23	626	7	32	200
101	UTAH LAKE	4490	80877	5.4	47	41	33	221738	6	10	22174
102	COLUMBIA STEEL COMPANY	4500	205	3.9	44	39	31	526	6	24	126
103	'PROVO'	4490	60	3.9	44	39	31	154	6	18	28
104	THIRTY OAKS	5200	400	3.5	56	49	39	1307	6	26	340
105	STRAWBERRY RESERVOIR	7590	12680	4.6	37	32	26	26977	5	16	4316
106	LAKE BOREHAM	5300	100	3.9	46	40	32	265	3	17	45
107	BIG SAND WASH	6000	196	3.1	34	29	23	383	7	32	123
108	STARVATION	5800	2648	3.9	44	38	30	6699	7	27	1809
109	FLAMING GORGE RESERVOIR	6000	27700	4.2	43	38	30	69481	8	22	15286
110	DAGGETT LAKE	10600	35	3.3	17	15	12	35	5	12	4
111	WHITEROCKS RESERVOIR	10600	56	3.3	17	15	12	56	5	18	10
112	JOHNSON LAKE	10400	1064	4.4	18	16	13	1117	5	22	246
113	TWIN LAKES	10100	39	3.3	17	15	12	39	5	12	5
114	LONE PARK RESERVOIR	10000	50	3.5	18	16	13	53	5	18	9
115	OAKS PARKS RESERVOIR	9400	306	3.9	23	20	16	411	6	24	99
116	EAST PARK RESERVOIR	9000	132	3.7	24	21	17	185	5	24	44
117	CALDER POND	7600	78	4.4	27	24	19	123	6	18	22
118	CROUSE RESERVOIR	7160	109	3.9	27	24	19	172	5	22	38

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION ANNUAL (INCHES)	LAKE EVAPORATION SEASONAL (INCHES)	LAKE EVAPORATION SEASONAL (AC FT)	MONOLAYER MODEL SITE FACTOR	MONOLAYER MODEL PERCENT SUPPRESSION	MONOLAYER MODEL SALVAGE (AC FT)
119	'GREEN RIVER'	5600	26	3.9	41	36	29	62	4	10	6
120	TWIN LAKES RESERVOIR	5600	293	3.1	40	35	28	684	4	24	164
121	PARADISE PARK RESERVOIR	10000	114	3.3	17	15	12	113	5	24	27
122	STEINAKER RESERVOIR	5600	656	3.1	39	34	27	1492	4	24	358
123	STUART LAKE	5000	243	2.6	36	32	25	510	5	30	153
124	MONTEZ CREEK RESERVOIR	5320	45	3.5	45	39	31	116	4	11	13
125	PELICAN LAKE	4800	571	3.1	49	42	34	1609	3	22	354
127	GRANITE RESERVOIR	5000	49	5.7	47	41	33	134	4	8	11
128	GUNNISON BEND	4600	562	7.9	56	48	39	1810	2	7	127
129	SEVIER BRIDGE RESERVOIR	5015	2950	7.9	58	50	40	9838	3	9	885
130	CARR LAKE	4500	26	5.7	52	45	36	78	3	7	5
131	'VAN'	4600	39	5.7	52	45	36	117	4	8	9
132	CLEAR LAKE	4600	1330	5.7	52	45	36	3977	4	16	636
133	SCIPIO LAKE	6000	300	5.3	44	38	30	759	3	14	106
134	FOOL CREEK RESERVOIR NO. 1	4800	200	7.9	56	48	39	644	5	13	84
135	FOOL CREEK RESERVOIR NO. 2	4800	326	7.9	56	48	39	1050	5	13	136
137	DMAD	4700	599	7.9	56	48	39	1929	5	13	251
138	SUMMIT CREEK RESERVOIR	5000	71	3.1	52	45	36	212	4	18	38
139	MONA RESERVOIR	5000	1557	4.4	47	41	32	4208	3	16	673
140	LOWER GOOSEBERRY RES.	8400	32	3.1	25	22	17	46	5	13	6
141	SCOFIELD RESERVOIR	7590	2520	5.0	38	33	26	5506	4	17	936
143	FISH SPRINGS	3800	7200	9.0	71	62	50	29820	4	8	2386
144	CHICKEN CREEK RESERVOIR	5100	323	4.8	48	41	33	891	3	14	125
145	WALES RESERVOIR	5600	130	3.7	42	36	29	314	4	22	69
146	ELECTRIC LAKE	8400	352	4.4	26	22	18	526	5	22	116
147	HUNTINGTON RESERVOIR	9000	200	4.4	25	22	17	288	5	22	63

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION			MONOLAYER MODEL		
						ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	SITE FACTOR	PERCENT SUPPRESSION	SALVAGE (AC FT)
148	MILLER FLAT	8900	128	4.4	25	22	17	184	5	22	40
149	CLEVELAND RESERVOIR	9000	110	4.4	25	22	17	158	5	22	35
150	ROLF SON RESERVOIR	9000	45	4.4	25	22	17	65	5	11	7
151	'WHITMORE'	7000	24	4.4	38	33	26	52	5	11	6
152	TOPAZ SLOUGH	4500	830	7.9	56	48	39	2673	4	11	294
153	DESERT LAKE	5500	544	4.4	36	31	25	1126	4	19	214
154	OLSEN RESERVOIR	5500	40	4.4	36	31	25	83	5	11	9
155	GUNNISON RESERVOIR	5400	1136	3.9	50	43	35	3266	3	17	555
156	FUNKS LAKE	6000	150	4.4	40	35	28	345	6	24	83
157	FERRON RESERVOIR	9600	60	3.3	20	17	14	69	5	18	12
158	NINE MILE RESERVOIR	5500	167	4.4	43	37	30	413	6	24	99
159	BUCKHORN RESERVOIR	5900	38	3.9	40	35	28	87	4	10	9
160	WILLOW CREEK RESERVOIR	5800	20	3.5	54	47	37	62	6	13	8
161	ISLAND LAKE	9600	34	4.4	19	16	13	37	5	11	4
162	MILLSITE	6400	348	4.4	44	38	30	868	5	22	191
163	GRAND CANYON P.C.	4200	1151	3.1	72	63	50	4765	4	24	1144
164	TOWAVE RESERVOIR	6600	16	3.3	37	32	26	34	6	13	4
165	HERCULES RESERVOIR	4900	211	3.9	52	46	36	631	3	17	107
166	COTTONWOOD RESERVOIR	4500	731	3.9	60	52	41	2485	4	20	497
167	'CUDAHY'	5200	16	5.3	46	40	31	42	3	7	3
168	DUTCHMAN RESERVOIR	4800	13	5.3	53	46	36	39	4	8	3
169	NEWHOUSE RESERVOIR	4800	13	5.3	53	46	36	39	4	8	3
170	THREE CREEKS RESERVOIR	6900	46	3.5	30	26	20	78	5	12	9
171	'RANCH'	4920	13	9.0	69	60	47	51	2	3	2
172	BIG WASH RESERVOIR	5800	56	4.8	39	34	27	124	5	14	17
173	BARNEY LAKE	9600	19	3.5	21	18	14	23	5	12	3

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION ANNUAL (INCHES)	LAKE EVAPORATION SEASONAL (INCHES)	LAKE EVAPORATION SEASONAL (AC FT)	SITE FACTOR	MONOLAYER MODEL PERCENT SUPPRESSION	MONOLAYER MODEL SALVAGE (AC FT)
174	MINERSVILLE RESERVOIR	5600	760	5.3	47	41	32	2024	4	16	324
175	PUFFER LAKE	9800	60	3.5	21	18	14	71	5	18	13
176	PIUTE RESERVOIR	5995	1480	4.5	50	44	34	4193	5	22	923
177	OTTER CREEK RESERVOIR	6350	2200	4.3	38	33	26	4737	5	22	1042
178	ROCKY FORD RESERVOIR	5400	903	4.8	42	36	29	2149	7	24	516
179	REDMOND LAKE	5200	22	3.7	52	45	36	66	5	12	8
180	SKUMOAH RESERVOIR	8000	24	3.1	26	23	18	36	5	13	5
181	SHEEP VALLEY	8800	69	3.5	25	22	17	98	5	18	18
182	KOOSHAREM RESERVOIR	7100	321	4.0	33	28	22	600	2	15	90
183	JOHNSON VALLEY RESERVOIR	9000	610	4.0	35	31	24	1210	4	20	242
184	FISH LAKE	9000	2522	4.0	35	31	24	5002	4	20	1000
185	FORSYTH RESERVOIR	8000	137	3.1	33	29	22	256	6	30	77
186	MILL MEADOW RESERVOIR	7800	75	3.1	34	30	23	145	6	22	32
187	BOTTLE HOLLOW	4800	418	3.1	49	42	34	1178	4	24	283
188	THURBER RESERVOIR	7000	2596	3.5	39	34	27	5737	5	24	1377
189	'LOOKOUT PEAK'	11000	30	3.5	18	16	12	31	5	12	4
190	'DONKEY MEADOWS'	9800	30	3.5	20	17	14	34	5	12	4
191	DONKEY RESERVOIR	9900	32	3.5	20	18	14	36	5	12	4
192	JACOBS RESERVOIR	10000	288	3.5	20	18	14	326	5	24	78
193	MCGATH LAKE	9600	48	3.5	21	19	14	57	5	12	7
194	'EAST MCGATH'	9600	30	3.5	21	19	14	36	5	12	4
195	SPECTACLE LAKE RESERVOIR	10900	200	3.5	19	17	13	215	5	24	52
196	GRASS LAKE	9800	30	3.5	20	18	14	34	5	12	4
197	OAK CREEK RESERVOIR	10000	32	3.5	20	18	14	36	5	12	4
198	DEER CREEK LAKE	10000	64	3.5	20	18	14	73	5	18	13
199	BOWNS RESERVOIR	6400	30	3.5	33	29	22	56	5	12	7

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	SITE FACTOR	MONOLAYER MODEL PERCENT SUPPRESSION	SALVAGE (AC FT)
200	VALLEY CITY RESERVOIR	4800	40	3.1	48	42	33	109	6	15	16
201	HOOSIER LAKE	8600	159	3.7	24	21	16	216	5	24	52
202	PARAGUNAH RESERVOIR	5800	85	4.4	43	37	29	207	4	14	29
203	RED CREEK RESERVOIR	7800	40	3.1	30	26	20	68	5	13	9
204	YANKEE MEADOWS RESERVOIR	8800	48	3.7	23	20	16	63	5	12	8
205	QUICHAPA LAKE	5600	622	4.4	41	36	28	1445	3	16	231
206	PANGUITCH LAKE	8400	1238	4.4	41	36	28	2876	6	24	690
207	ROUNDY RESERVOIR	7800	94	3.3	25	22	17	133	5	18	24
208	'BLUE SPRING'	9600	19	3.3	25	22	17	27	5	12	3
209	LOWER ENTERPRISE RESERVOIR	5800	49	4.4	43	38	29	119	8	14	17
210	ENTERPRISE RESERVOIR	5800	268	3.9	47	42	32	714	7	27	193
211	KOLOB RESERVOIR	8095	200	3.7	32	27	21	347	6	26	90
212	MAMMOTH CREEK RES.	7600	491	3.5	26	23	18	723	5	24	174
213	NAVAJO LAKE	9000	582	4.4	24	21	16	792	7	26	206
214	TROPIC LAKE RESERVOIR	8000	120	3.9	27	24	18	184	8	30	55
215	UPPER SAND COVE RES.	4400	20	3.9	59	50	38	64	4	10	6
216	GRASS VALLEY CREEK	9000	780	3.2	21	19	14	928	5	27	251
217	BAKER DAM RESERVOIR	5000	41	3.3	50	45	34	116	7	14	16
218	ASH CREEK RESERVOIR	4830	193	4.8	51	46	35	558	6	21	117
219	LE VANGEN LAKES	7000	30	4.2	48	42	33	82	5	11	9
220	'S.C. BENCH'	3200	30	4.4	74	64	48	120	4	9	11
221	CYCLONE LAKE	10000	30	3.5	20	18	14	34	5	12	4
222	PINE LAKE	7800	66	3.5	26	23	18	97	5	18	18
223	LAKEVIEW	8800	24	3.9	24	21	16	33	5	11	4
224	WIDE HOLLOW RESERVOIR	6000	96	3.5	51	45	35	277	5	18	50
225	LAKE POWELL	3700	114000	4.4	79	68	51	487825	8	14	68295

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION			MONOLAYER MODEL		
						ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	SITE FACTOR	PERCENT SUPPRESSION	SALVAGE (AC FT)
226	DUCK LAKE	7400	582	3.5	28	25	19	923	5	24	222
227	BLUE MOUNTAIN	6900	163	4.4	46	42	31	425	4	19	81
228	JONES RESERVOIR	7000	130	4.4	46	42	31	339	3	16	54
230	JOE.S VALLEY RESERVOIR	7000	867	3.1	29	25	20	1446	4	24	347
231	DOG VALLEY	7500	288	3.5	28	24	19	457	4	22	101
232	PRUESS	5400	200	5.7	57	50	39	656	4	16	105
233	BIG LAKE	8600	113	3.2	23	20	16	147	5	27	40
235	FARMINGTON BAY	4204	3161	4.0	52	46	37	9725	4	20	1945
236	HOWARD SLOUGH	4204	2300	4.0	52	46	37	7076	4	20	1415
237	RAINBOW CLUB	4204	192	4.0	52	46	37	591	4	20	118
238	SAGEBRUSH CLUB	4204	203	4.0	52	46	37	625	4	20	125
239	DUCKVILLE CLUB	4204	90	4.0	52	46	37	277	4	15	42
240	CHESAPEAKE CLUB	4204	565	4.0	52	46	37	1738	4	20	348
241	BEAR RIVER CLUB	4204	5469	4.0	52	46	37	16826	4	20	3365
242	NORTH PT. FUR CLUB	4204	136	4.0	52	46	37	418	4	20	84
243	LAKE FRONT CLUB	4204	57	4.0	52	46	37	175	4	15	26
244	RUDY CLUB	4204	565	4.0	52	46	37	1738	4	20	348
245	HARRISON CLUB	4204	328	4.0	52	46	37	1009	4	20	202
246	UTAH CLUB	4204	34	4.0	52	46	37	105	4	10	10
247	GUNLOCK RESERVOIR	3600	208	3.9	82	71	53	924	5	22	203
	FRESH WATER TOTALS		436765					1325318			195318
	FRESH WATER AVERAGES			4.1		33	26		5	18	

NO.	NAME	ELEV	EFFECTIVE AREA (ACRES)	SEASONAL 2M WIND (MPH)	SEASONAL PAN EVAP (INCHES)	LAKE EVAPORATION ANNUAL (INCHES)	SEASONAL (INCHES)	SEASONAL (AC FT)	MONOLAYER MODEL SITE FACTOR	PERCENT SUPPRESSION	SALVAGE (AC FT)
226	DUCK LAKE	7400	582	3.5	28	25	19	923	5	24	222
227	BLUE MOUNTAIN	6900	163	4.4	46	42	31	425	4	19	81
228	JONES RESERVOIR	7000	130	4.4	46	42	31	339	3	16	54
230	JOE.S VALLEY RESERVOIR	7000	867	3.1	29	25	20	1446	4	24	347
231	DOG VALLEY	7500	288	3.5	28	24	19	457	4	22	101
232	PRUESS	5400	200	5.7	57	50	39	656	4	16	105
233	BIG LAKE	8600	113	3.2	23	20	16	147	5	27	40
235	FARMINGTON BAY	4204	3161	4.0	52	46	37	9725	4	20	1945
236	HOWARD SLOUGH	4204	2300	4.0	52	46	37	7076	4	20	1415
237	RAINBOW CLUB	4204	192	4.0	52	46	37	591	4	20	118
238	SAGEBRUSH CLUB	4204	203	4.0	52	46	37	625	4	20	125
239	DUCKVILLE CLUB	4204	90	4.0	52	46	37	277	4	15	42
240	CHESAPEAKE CLUB	4204	565	4.0	52	46	37	1738	4	20	348
241	BEAR RIVER CLUB	4204	5469	4.0	52	46	37	16826	4	20	3365
242	NORTH PT. FUR CLUB	4204	136	4.0	52	46	37	418	4	20	84
243	LAKE FRONT CLUB	4204	57	4.0	52	46	37	175	4	15	26
244	RUDY CLUB	4204	565	4.0	52	46	37	1738	4	20	348
245	HARRISON CLUB	4204	328	4.0	52	46	37	1009	4	20	202
246	UTAH CLUB	4204	34	4.0	52	46	37	105	4	10	10
247	GUNLOCK RESERVOIR	3600	208	3.9	82	71	53	924	5	22	203
	FRESH WATER TOTALS		436765					1325318			195318
	FRESH WATER AVERAGES			4.1		33	26		5	18	