Project Proposal:
Landscape Scale Treatments for Snowpack Management

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1.0 Project Understanding

1.1 Purpose of the Project

The purpose of this project is to investigate and test at the "study plot" scale landscape scale treatments for snowpacks that minimize sublimation losses of snow water resources back into the air, leading to an increase in snowmelt that can make it into surface water flows and water supply storage facilities that are filled by snowmelt runoff.

1.2 Background

The field of water resources has never been as important as it is today, especially in the western United States where growing populations are placing a large demand on the area's water supply. This large demand for water in the western United States is exacerbated by a current 11 year drought. This has put increased pressure on limited water resources in the arid climate because water supply storage facilities are not being fully recharged by surface waters. Additionally, less than ten percent of the total precipitation that does fall in the Southwest is actually regained and used by people[1]. The majority of the precipitation evaporates, sublimates, or is absorbed by the soil matrix. If an increase in precipitation retention could be made, more water could be available for use by the population in the western states.

Much of the surface waters in the western United States are fed by runoff from winter snowpacks. Snowpacks are especially important because they store large amounts of water and release it slowly over the year, allowing many surface water supplies to be available year round. If the amount of snow water lost through sublimation is limited by a treatment, more runoff will find its way into surface waters where it can be recovered for use. Snowpacks should be the focus of a treatment to increase the amount of precipitation recovered because rain is not retained as well as snow, which makes it less feasible for treatment.

1.3 Current Conditions

Currently, there are several techniques that can be implemented to help increase snow precipitation, increase peak snowpack, or slow the melting process of the snowpack. Cloud seeding is a method that promotes an increase in snow precipitation. It does so by supplying an ice nucleus for snow precipitation to form around, supporting the creation of snowflakes[2]. This method is widely used in the western United States.

Tree thinning is a forestry management practice that can increase peak snowpack because greater amounts of snow accumulate on the ground in lower-density forests[1]. A low density forest is a forest that has ample room for growth due to natural conditions or human interactions. In the Beaver Creek watersheds, roughly 80 km south of Flagstaff, vegetative management practices such as clear cutting, tree thinning, and cutting out strips of forest, were tested on several different forest types (ponderosa pine, alligator juniper, and Utah juniper) to determine their effect on annual water yield[3]. All of these management practices led to increases in annual water yields ranging from 30 to 160 percent. Because 85 percent of annual water yield comes from the average winter runoff, the results are directly related to how the management practices affected winter snowpack[3].

Methods that prolong winter snowpack include managing wind-driven snow and treating the snowpack before the melt season. Fences can be used to encourage the accumulation of snow in specific areas, leaving large drifts that last long into the melting season. Treatment, such as spreading wood chips over the snowpack before the melt season begins, slows the evaporation and sublimation of snow. This method has been tested but not applied significantly to various terrains or to landscape-size treatments[4].

All of these methods must be applied with consideration of forest health; a higher quantity of snowpack coincides with a healthy forest. A low density forest, which is considered healthy in Arizona, will allow for more snowpack and less environmental stresses like forest fires, insect infestation, and disease[5]. However, low density forests have higher rates of soil erosion and a lack of forest fires may slow the regrowth of fire-adapted seeds[6].

1.4 Project Requirements

In order to ascertain which treatments will be effective, Snowpack Engineering will perform several small scale experiments. These experiments will test the effectiveness which a treatment might have at preventing snowpack sublimation. The experiment will be set up to ensure that a testable quantity of snow will be treated. The treatments will then be applied to the snow in study plots which will be monitored daily. Snowpack Engineering will correlate data such as temperature, wind speed, and relative humidity, with the snowpack characteristics such as snow depth, snow density, and snow water equivalent to determine effective treatments. The resulting data will then be compared to an untreated plot of snow which will act as a control to the experiment.

For a snowpack treatment to be a candidate for landscape scale implementation it will need to be effective as well as cost efficient. Treatments which can reliably increase seasonal snowmelt in watersheds where much of the snowmelt makes it into surface flows would be considered successful. Additionally, the treatments need to be tested on two different landscapes. A study area representative of a meadow and a thinned forest will be used to determine where each treatment will be most effective. Then, optimal watersheds for the treatment will be identified based upon how effective they are at channeling precipitation into surface water. Watersheds in the Upper and Lower Basin, specifically in northern and eastern Arizona, will be targeted for treatment. Finally, the cost of each treatment applied on the landscape scale will be established.

1.5 Project Success

The most important factors in the quality of the treatment will be its effectiveness, cost, and ease of implementation on a landscape scale. Additionally, there is a need for creative solutions that will maintain the native biodiversity and ecological processes of the landscape to which the treatments are applied.

1.6 Stakeholders

An application of an effective treatment to a snow basin will not only delay the arrival of snowmelt to a water storage basin, it will also increase the volume of water reaching the storage basin. The delivery of more water to water storage reservoirs, within a cost effective range, will be useful locally and globally, by any society dependent on snowmelt. Effective and cost efficient treatments that have been tested on a landscape scale will be of interest to water resources management organizations, or water providers, who rely primarily upon water derived from snowmelt runoff. This includes groups such as the Central Arizona Project (CAP), Metropolitan Water District of Southern California (MWDSC) and the Utah Department of Water Resources (UDWR). Dr. Rand Decker of Northern Arizona University is sponsoring and funding this project with additional interest from the Salt River Project of Arizona.

1.7 Project Timeline

The experimental design that will be utilized to develop potential treatments will be designed between November 2010 and January 2011. This will allow for the identification and preparation of study plots so that testing can begin in January and extend into March 2011. Results will be analyzed in March and April 2011 and will be presented in a final report and presentation at the end of April 2011.

1.8 Challenges

Potential challenges that the design team anticipates:

- Designing a meaningful experiment that produces applicable data
- Determining and obtaining locations for the experiment's study plots
- Adapting to and working around weather conditions
- Minimizing negative environmental effects, if possible

The team will address these challenges by working hard to design a well-planned experiment in advance of implementing it in the field. This will help maximize the use of limited time for data collection. Detailed documentation will be kept to assist in the application of sample data to a landscape scale. Furthermore, the team will attempt to be ready before the first significant snowfall so that the weather and time can be utilized to its full potential. If necessary, the team will travel to locations to encounter the weather conditions required for the experiment.

2.0 Scope of Services

The purpose of this study is to identify, through study plot scale experimentation, a number of treatments that can be implemented at the landscape scale to limit the amount of water lost due to sublimation of snowpack. Limiting sublimation losses of snowpack will allow for an increase in the amount of water that is available to water resource managers who rely primarily on surface waters derived from snowpack. Snowpack Engineering proposes that this study be divided into the following tasks to identify effective snowpack treatments. The project tasks will be as follows:

- Task 1- Project Management
- Task 2- Research and Background
- Task 3- Experiment Design

- Task 4- Experimental Setup and Data Collection
- Task 5- Data Analysis
- Task 6- Cost Analysis
- Task 7- Results and Recommendations
- Task 8- Presentation of Results

2.1 Task 1- Project Management

2.1.1 Snowpack Engineering Team Meetings

Team meetings are an important part of this project and will be the setting for most of the execution of the project and project deliverables. The purpose of team meetings is to identify project issues and address the status of the project. All team members will be expected to be present at all meetings which will take place, at minimum, once per week. Meetings will have an agenda that will be outlined by the team leader before each meeting.

To ensure quality, Snowpack Engineering will consult the project's Technical Advisor before submitting each deliverable. The Technical Advisor will give suggestions, check the validity of the project methodology, and review deliverables prepared by the design team. Snowpack Engineering will also be responsible for final review of all deliverables, which will be reviewed collectively by each team member before they are submitted.

Deliverables:

- **Meeting agendas and minutes for reference and review by Snowpack Engineering as well as the client**

2.1.2 Client Coordination Meetings

Snowpack Engineering will correspond with Dr. Rand Decker through client coordination meetings. The purpose of these meetings is: (a) to ensure that the execution of the project is on schedule and Dr. Decker is satisfied with the work being performed and (b) to discuss any issues that arise between the client and the design team. Client meetings will take place as determined necessary by Dr. Decker or Snowpack Engineering staff. Major project deliverables, such as the 30%, 60% and 90% completion reports will be delivered to the client during appropriate client coordination meetings as a means to keep the client informed of the status of the project.

Deliverables:

- **Meeting agendas and minutes for reference and review by Snowpack Engineering and as well as the client**
- **Presentation of 30%, 60% and 90% completion reports**
- **150-300 word abstract to be submitted to the Western Snow Conference**
- **Final report with completed research, background, methodology, data analysis, cost analysis and results and recommendations sections**

2.2 Task 2 - Research and Background

Task 2 will require Snowpack Engineering to research many broad topics in snow hydrology, with the ultimate goal of demonstrating the need for snowpack treatment to increase the amount of water in surface flows. The research in Task 2 will primarily consist of reading documents and interviewing snowpack hydrology experts. Research in snow hydrology will take place at the global, regional and local scale. Current treatments for limiting losses of snowpack due to sublimation will also be researched.

2.2.1 Research at Global and Regional Scale

The relationship between food and water supply, crop yield, forest health, human population and snowpack will be a few of the topics researched. This research will demonstrate the importance of snowpack on a global scale as well as how it pertains to the Colorado River Basin in the western United States. Because snowpack is the primary origin of the Colorado River, this research will focus on watersheds in the Colorado River Basin and water management groups who rely on snowmelt runoff in this region.

2.2.2 Research at Local Scale

The primary area of focus for this study is the watersheds which originate in the plateau and rim countries in northern and eastern Arizona. Major watersheds encompassed in this area are those of the Salt and Little Colorado Rivers. The relationship between food and water supply, crop yield, forest health, human population and snowpack will be researched as they pertain to these Arizona watersheds. In-depth research will be conducted to gain an understanding of current technologies used to measure snowpack. Additionally drainage basins which are efficient at putting snowmelt into surface waters within these regions will be identified. This will be done so that selected treatments can be applied where they will have the greatest impact at increasing surface water flows.

2.2.3 Current Treatments for Limiting Losses

Currently available and/or tested methods to limit snowpack sublimation losses will be researched in this task by Snowpack Engineering. This research will be conducted to identify established treatments as well as assist in the development of innovative treatments. The methods used to test treatments will be researched to assist in developing methodology to be used in this study.

Deliverables:

- **Background and research sections of final report and presentation in a research report format**

2.3 Task 3 – Experiment Design

The main purpose of this task will be to establish the experimental methodology for testing various treatments of snowpack. The experiment will be conducted based on decisions made in this task.

2.3.1 Experimental Methodology Design

The Experimental Methodology Design is where the design team will establish testing procedures which will be carried out on the study plot scale. The design of the experimental methodology will include the duration of the experiment, the time intervals for data collection, the plot setup, the design of the control plot, the parameters which will be tested, as well as materials and equipment needed.

2.3.1.1 Duration of the Experiment

The duration of the experiment will be established in this task. The design team will decide how long to collect data to accurately reflect rates of sublimation and effectiveness of treatments at reducing sublimation losses. We anticipate collecting data between winter storm events with as many trials as possible to optimize accuracy of the results. The design team will be ready to collect data starting February 1st, 2011, continuing on a per storm basis through March 13th, 2011.

2.3.1.2 Time Intervals for Data Collection

Snowpack Engineering anticipates collecting data twice daily, starting the first day after a storm event and continuing until the next storm event or until snowpack is negligible. Potential times might be in the mornings and evenings of each day. An effort will be made to collect data at the same time for each location.

2.3.1.3 Design of Plot Setup

Snowpack Engineering will design the plot layout for each location in this subtask. The plots will provide data which Snowpack Engineering will use to determine the rate of sublimation losses for each treatment. This task includes determining how the separate plots for each treatment and control plot will be arranged at the location. Issues that will be considered include maintaining consistency between plots, orienting the plots in the same direction, sizing the plots, and determining the distance between plots to prevent contamination between applied treatments.

2.3.1.4 Design of Control Plot

A control plot will be present at each location to represent snow that has not been treated by any methods. It will provide baseline rates of sublimation for comparison to the treated plots. It will be assumed that the conditions of the control plot are equal to the conditions of the treated plots; this will balance out any losses or additions of snow as result of wind, snowfall or other uncontrollable conditions.

2.3.1.5 Materials and Equipment Needed

Prior to beginning the experiment, the team will generate a list of necessary materials and equipment, including materials needed to construct the plots as well as equipment needed to determine sublimation losses.

2.3.1.6 Parameters that will be Monitored and Tested

Sublimation losses will be determined based on snowpack reduction. Snowpack Engineering will monitor snowpack reduction daily by recording air temperature, wind speed, relative humidity, snow density, snow depth, and snow water equivalent at each plot.

2.3.2 Location of Study Plots

The location of the actual study plots will be determined prior to January 18th, 2011. Locations will be selected to represent two different landscapes in the Colorado River Basin where snowpacks are annually present. Snowpack Engineering plans to test treatments on two landscapes: open meadows and thinned forests. The study plots will be located at nearly identical elevations and climates for control purposes.

2.3.3 Treatment Selection for Testing

Innovative and established treatments researched in Task 2 may be first tested in a controlled laboratory setting, if deemed necessary by Snowpack Engineering. Lab testing will take place if it is determined that the number of treatments needs to be reduced. The best treatments identified in the lab or through research will be selected for testing at the study plot scale. The established treatments which may be tested will include biomass blanketing, such as a biomass made of wood chips, and the compaction of snowpacks. The ultimate goal of this selection process will be to determine three treatments which will be best suited for testing at the study plot scale.

Lab testing of treatments will also be utilized to replace the study plot scale experiments if no major snowstorm events take place during the data collection period. To conduct these experiments, snow will be gathered from a local hockey rink or collected from a higher elevation. Wind speed, air temperature, and relative humidity will be controlled in the lab.

Deliverables:

- **Experimental methodology section of final report and presentation, which will outline the design and final processes of the experimental methodology**

2.4 Task 4 - Experimental Setup and Data Collection

2.4.1 Experimental Setup

After Snowpack Engineering has developed an experimental methodology, necessary design plot setups will be fabricated. This process will involve the construction and setup of the plots designed in Task 3. The fabrication and design of data collection plots will be completed by January 18th, 2011 when the data collection is scheduled to begin.

2.4.2 Data Collection

Data collection will take place in between storm events for the entire duration of the experiment as outlined in Task 3. As mentioned above, the data collection task will last from January 18th, 2011, to March 11th, 2011.

Deliverables:

- **Data sheets with collected data written in by hand as well as computer generated data sheets that will be used for data analysis**
- **Collected data as appendices to final report**
- **Pictures to supplement final presentation and report**

2.5 Task 5 - Data Analysis

Data collected during the experiment will be analyzed to determine the most effective treatment for limiting sublimation losses, and at which landscape the selected treatment will be more effective. Data will be analyzed to determine sublimation losses due to each treatment as compared to the control plot and the other snowpack treatments. Analysis will be conducted by comparing parameters used to test treatments developed in Task 3 of the project. This task will involve the use of computer software, most likely to be Microsoft Excel.

Deliverables:

- **Organized data tables, graphs and other necessary figures that will be present both in the data analysis section of the final report as well as the final presentation**

2.6 Task 6 – Cost Analysis

Treatment cost is one of the main components that will factor into Snowpack Engineering's final recommendation for a snowpack treatment. Analysis will involve determining both the cost of materials and cost of application of each treatment at a landscape scale. Ease of implementation at the landscape scale will also be considered in the cost analysis.

Deliverables:

- **Cost analysis in the form of tables and text that will be part of the cost analysis section of the final report and presentation**

2.7 Task 7 – Results and Recommendations

Based on the results of the data and cost analyses, Snowpack Engineering will identify an optimal treatment for snowpack on a landscape scale. Treatments identified will be accompanied with projections for an increase in annual water yield for ideal watersheds. The design team will make recommendations as to further testing of additional treatments that were either promising or not fully evaluated during this study.

Deliverables:

- **Results and recommendations in the form of text, which should appear in the conclusion section of the final report and presentation**

2.8 Task 8 – Presentation of Results

As reported in the Project Management section of this proposal, at the conclusion of this project, Snowpack Engineering will present complete documentation of all tasks in the form of a final report. Additionally, Snowpack Engineering will provide an oral and visual presentation for the client, as well as any other deliverables requested by the client and project management. Potentially, a presentation will be prepared for the spring 2011 Western Snow Conference in Lake Tahoe, California, and a paper could be made available for publication.

2.8.1 Presentation Preparation

A Microsoft PowerPoint presentation will be prepared for both the Western Snow Conference in Lake Tahoe, California as well as the Northern Arizona University Undergraduate Capstone Seminar. The PowerPoint presentation will be used as a supplement to oral presentations that will be given at the same time. It will be desired to have the same presentation for each conference, but some slight adjustments may need to be made.

Deliverables:

- **Microsoft PowerPoint presentation summarizing the final report and results of this project**

2.8.2 Poster Preparation

Along with a Microsoft PowerPoint presentation, a poster will also be created for presentation at the Western Snow Conference as well as the NAU Undergraduate Capstone Seminar. The poster will be a brief overview of the project and will emphasize the methodology and results and recommendations section of the final report.

Deliverables:

- **Poster summarizing the final report and results of this project**

2.9 Exclusions

The experiment will be designed to test a treatment's effectiveness at limiting sublimation losses from the snowpack. The experiment will not consider water quality issues or long-term environmental impacts as a result of the treatments developed during this study. Additionally, obtaining necessary permits from any authorizing agency, as well as Environmental Assessments or Environmental Impact Statements will not be addressed in the scope of the project.

2.10 Regulatory Environments

Before implementation at a landscape scale, it will be the client's responsibility to seek approval from any relevant environmental agencies. At the local scale, approval may be needed from managers of local watersheds at the county or tribal level. Additionally, state regulators such as the Arizona Bureau of Land Management and Arizona Department of Environmental Quality would be consulted prior to applying the treatment on a landscape scale. These state agencies function to satisfy the requirements of the National Environmental Policy Act (NEPA) and other state or federal laws and regulations. At the federal level, the United States Forest Service (USFS), Environmental Protection Agency (EPA) and United States Geological Survey (USGS) could potentially need to be consulted and necessary permits acquired.

3.0 Project Schedule and Staffing Plan

3.1 Project Schedule

A detailed project schedule was developed by Snowpack Engineering. A summarized table with the main project tasks as identified in the project scope of services is shown in Table 1 below.

Table 1: Main Tasks

Main Tasks	Start Date	End Date
2.1 Project Management	November 22, 2010	April 29, 2011
2.2 Research and Background	November 22, 2010	April 4, 2011
2.3 Experiment Design	November 22, 2010	February 2, 2011
2.4 Experimental Setup and Data Collection	January 17, 2011	March 18, 2011
2.5 Data Analysis	March 21, 2011	April 27, 2011
2.6 Cost Analysis	March 29, 2011	April 27, 2011
2.7 Results and Recommendations	April 7, 2011	April 27, 2011
2.8 Presentation of Results	April 11, 2011	April 29, 2011

Key milestones are shown in the table on the following page. These key milestones encompass presentations and documentation to be submitted to the client, as well as a presentation at the 2011 Western Snow Conference and at the NAU Undergraduate Capstone Seminar.

Table 2: Key Milestones

Milestones	Date
Abstract	January 15, 2011
30 Percent Completion	February 15, 2011
60 Percent Completion	March 15, 2011
90 Percent Completion	April 12, 2011
Snow Conference Presentation	April 18, 2011
Final Document	April 28, 2011
NAU Undergraduate Presentation	April 29, 2011

The final project schedule was developed from information presented in the above tables. The final project schedule illustrates all main tasks and key milestones presented above, as well as key task activities and task dependencies.

Task dependencies imply the necessary completion of one task prior to the start of another. Important task dependencies are highlighted in Table 3 below. This table illustrates the major dependencies as determined by Snowpack Engineering. Additionally, all documentation sections will be dependent upon the completion of the corresponding tasks which they represent. These were left out of the summary table to keep the table simple and readable.

Table 3: Key Task Dependencies

Task Start:	Dependent Upon Completion of:
Treatments Selection for Testing	Research Current Treatments
Experimental Setup and Data Collection	Experimental Design
Data Collection	Experiment Setup
Data Analysis	Experimental Setup and Data Collection
Cost Analysis	Data Analysis
Results and Recommendations	Data Analysis and Cost Analysis

According to the determined schedule, the project will take about 23 weeks. The project will start on November 22, 2010 with the Project Management, Research and Background, and the Experiment Design tasks, and will end on April 29, 2011 with the Presentation of Results. The duration of the project as presented in the final project schedule is represented in work days, assuming the team works 5 days each week of the project. The project schedule was made to be flexible with regards to the Data Collection and Analysis tasks, as these are fairly dependent on the weather. The final project schedule is presented on the following page.

Insert Project Schedule

3.2 Staffing Plan

A detailed staffing plan was developed to show the workload division between each member of Snowpack Engineering. The general division will have each team member contributing equally to the Project Management tasks and deliverables as well as the Experiment Setup and Data Collection. In addition, Kevin Werbylo will generally serve as the Project Leader and will oversee the work of the project engineers as well as contribute to additional tasks such as the Cost Analysis and Results and Recommendations, as outlined in the project schedule. Adam Bringhurst and Keri Williamson will be the primary Project Engineers and will complete the majority of the Research and Background and Data Analysis tasks. For the most part, the deliverables will be written by two members of the team and checked by the third.

Table 4 on the following page presents the total hours required for each task as well as workload division between team members. The project will require a total of 513 hours with each member working 171 hours over the course of the project.

Table 4: Staffing Plan

Task Name	Hours			
	Total	Adam Bringhurst	Keri Williamson	Kevin Werbylo
2.1 Project Management				
2.1.1 Snowpack Team Meetings	69	23	23	23
2.1.2 Client Coordination Meetings	34.5	11.5	11.5	11.5
Deliverable: Abstract	3	1	1	1
Deliverable: 30% Completion	12	4	4	4
Deliverable: 60% Completion	12	4	4	4
Deliverable: 90% Completion	12	4	4	4
Deliverable: Final Documentation	3	1	1	1
2.2 Research and Background				
2.2.1 Research at Global and Regional Scale	40	0	30	10
2.2.2 Research at Local Scale	40	30	0	10
2.2.3 Current Treatments for Limiting Losses	3	1	1	1
Deliverable: Background Section of Final Report	6	2.5	2.5	1
2.3 Experiment Design				
2.3.1 Experimental Methodology Design	6	2	2	2
2.3.1.1 Duration of the Experiment	3	1	1	1
2.3.1.2 Time Intervals for Data Collection	3	1	1	1
2.3.1.3 Design of Plot Setup	12	4	4	4
2.3.1.4 Design of Control Plot	3	1	1	1
2.3.1.5 Materials and Equipment Needed	6	2	2	2
2.3.1.6 Parameters that will be Monitored and Tested	3	1	1	1
2.3.2 Locate Study Plots	6	2	2	2
2.3.4 Treatment Selection for Testing	20	5	5	10
Deliverable: Methodology Section of Final Report	6	2.5	2.5	1
2.4 Experimental Setup and Data Collection				
2.4.1 Experiment Setup	45	15	15	15
2.4.2 Data Collection	57	19	19	19
Deliverable: Collected Data Section of Final Report	4	0	1	3
2.5 Data Analysis				
Data Analysis	40	15	15	10
Deliverable: Data Analysis Section of Final Report	4	3	0	1
2.6 Cost Analysis				
Cost Analysis	10	1	1	8
Deliverable: Cost Analysis Section of Final Report	4	1	3	0
2.7 Results and Recommendations				
Results and Recommendations	6	1	1	4
Deliverable: Conclusions Section of Final Report	6	1	1	4

Table 5 Continued: Staffing Plan

2.8 Presentation of Results				
2.8.1 Presentation Preparation	15	5	5	5
Deliverable: Snow Conference Presentation	3	1	1	1
2.8.2 Poster Preparation	15	5	5	5
Deliverable: NAU Undergraduate Conference Presentation	1.5	0.5	0.5	0.5
Hours per Person	**513**	**171**	**171**	**171**

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Title Page Photograph: Chuck Lawsen. <http://www.chucklawsen.com/Mountains/Mountains/8739188_Brobq/1/584643752_yYGQx#584643752_yYGQx>. 2010.

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