Summary of Cloud Seeding Feasibility/Design Study

performed for

Idaho Water Resource Board

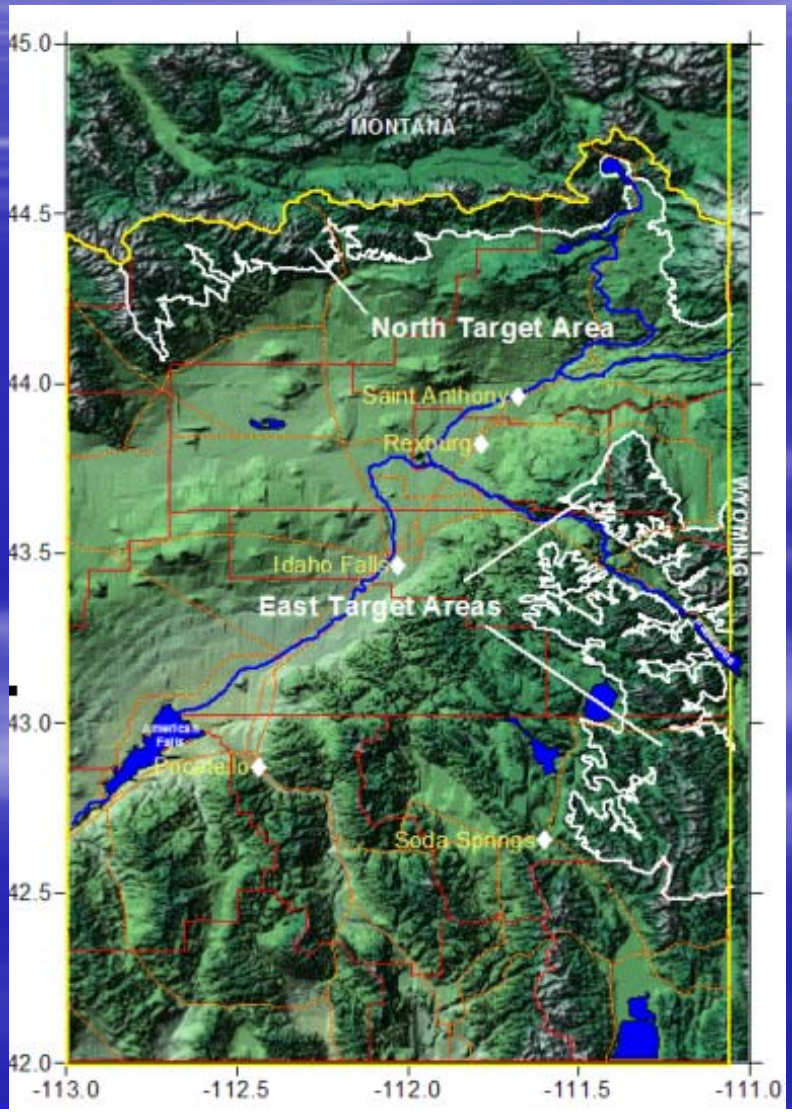
by

North American Weather Consultants
Sandy, Utah

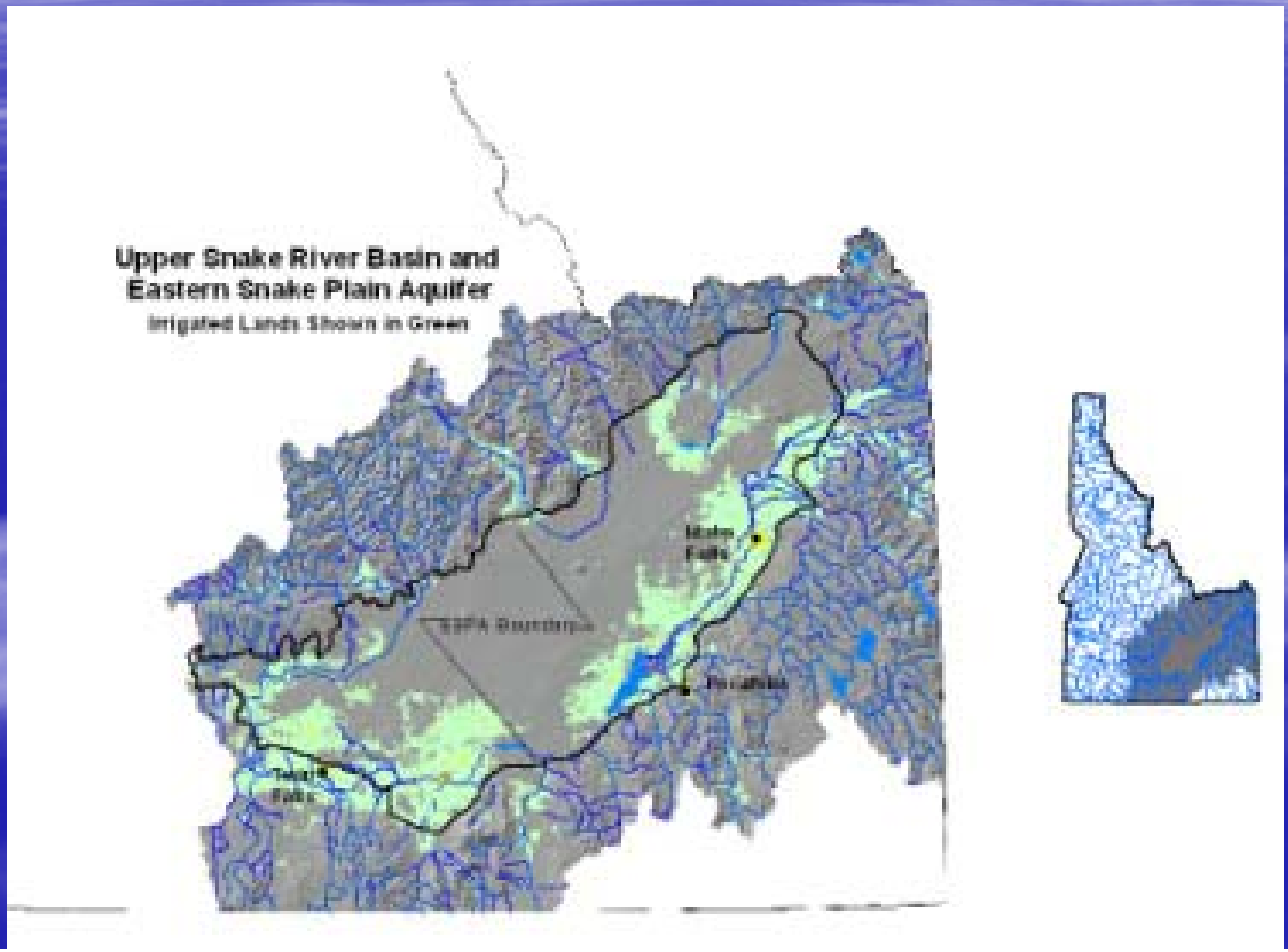
Contract Tasks

- Review and Summary of Prior Studies and Research (Task 1)
- Review and Analysis of Climatology of Target Area (Task 2)
- Development of a Preliminary Program Design (Task 3)
- Establishment of Operational Criteria (Task 4)
- Development of Monitoring and Evaluation Methodology (Task 5)
- Review of Environmental and Legal Aspects (Task 6)
- Development of Cost Estimates (Task 7)
- Report Preparation (Task 8)
- Coordination Meetings and Presentations (Task 9)
- Statistical Analysis of 2007-2008 Winter Cloud Seeding Project in Eastern Idaho (Task 10)

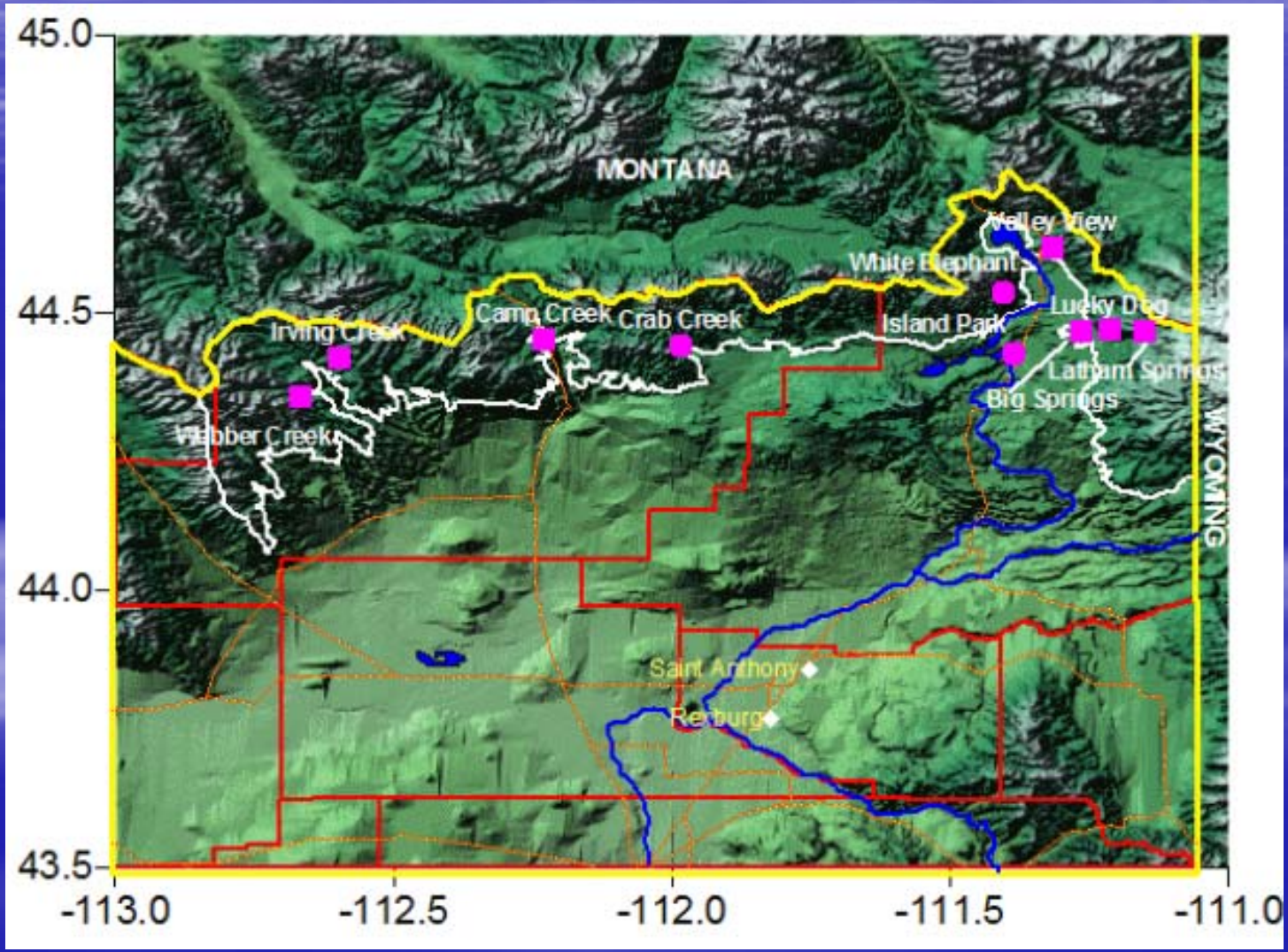
POTENTIAL TARGET AREAS ABOVE 6500 FEET



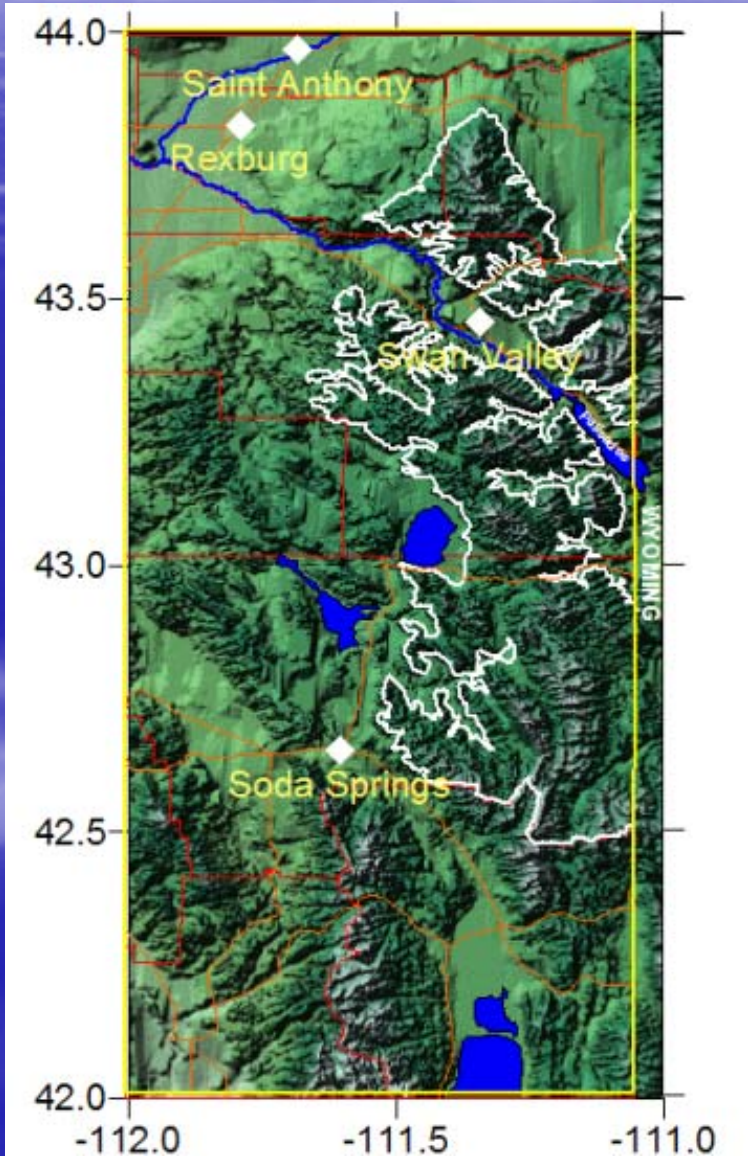
Region of Interest



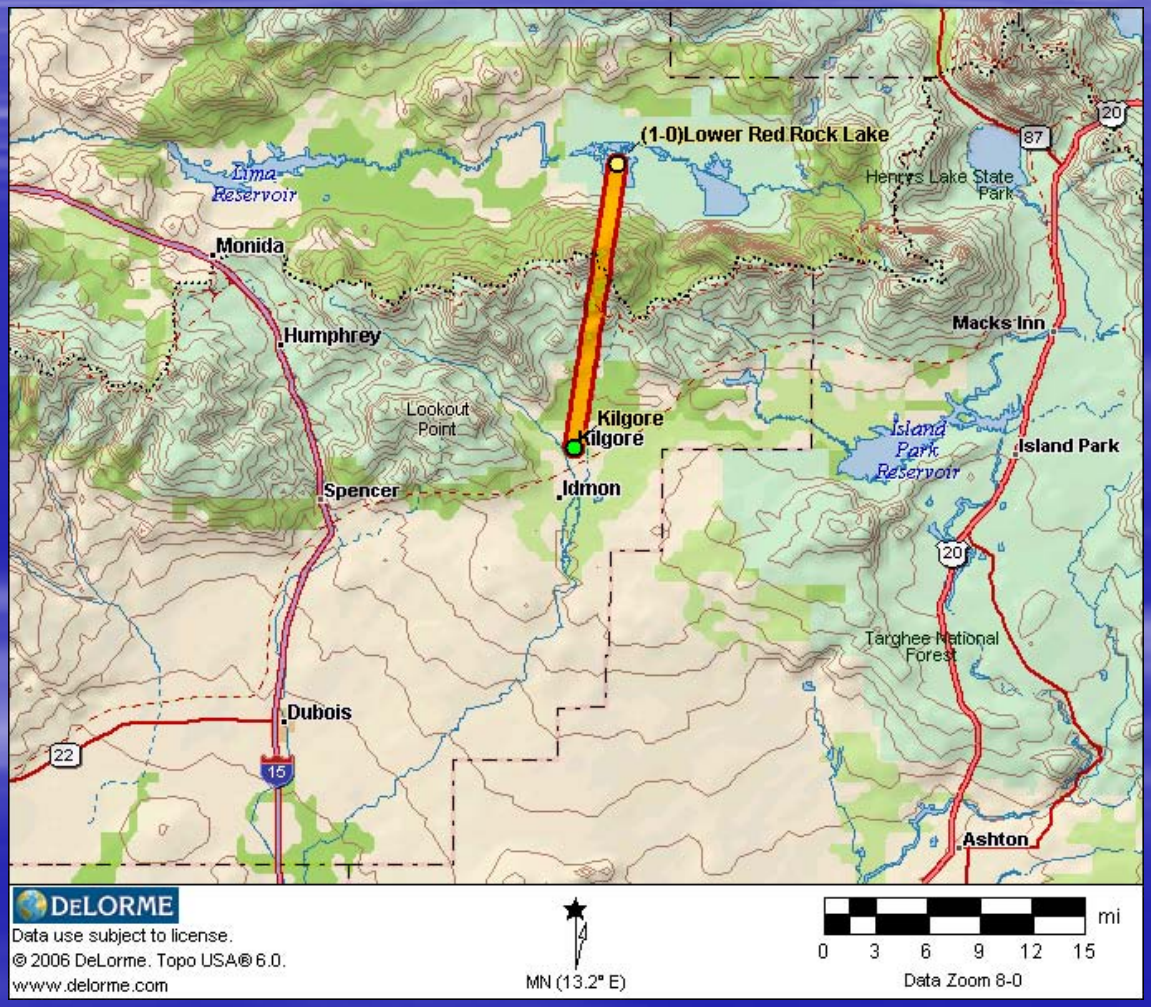
Potential North Target Area
(area above 6500 feet)



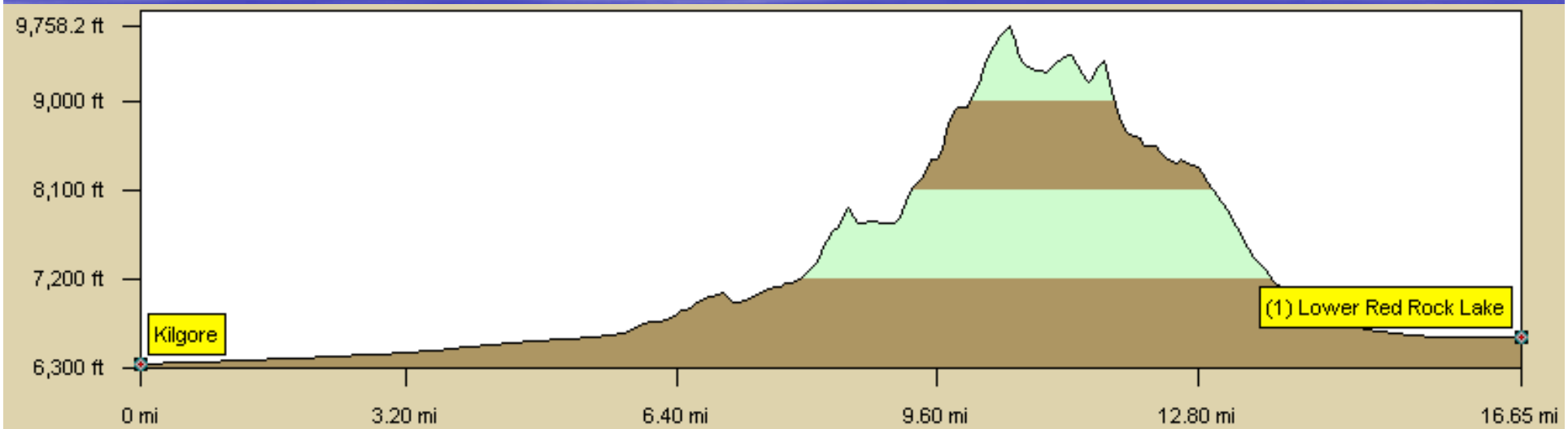
Potential East Target Area
(area above 6500 feet)



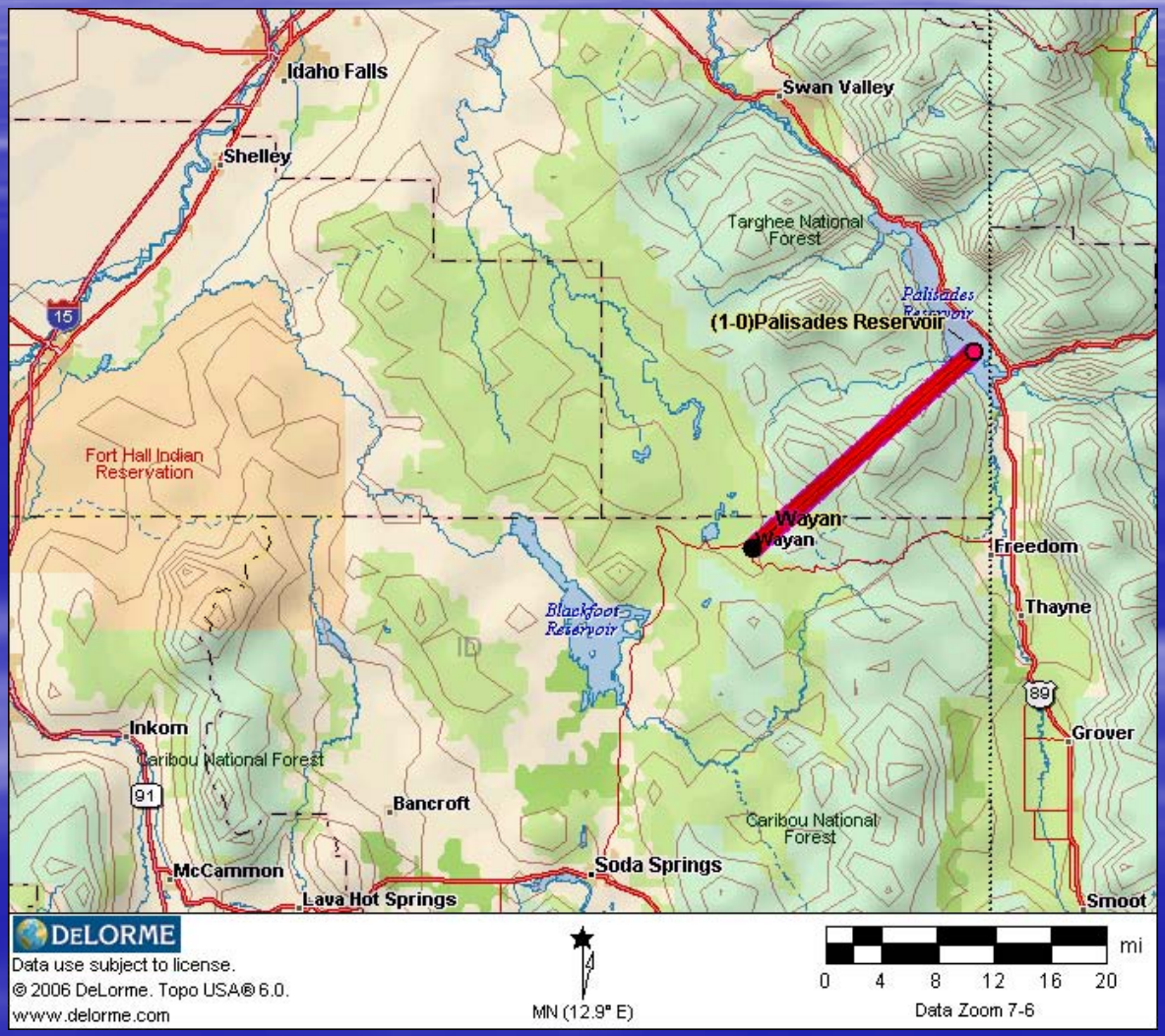
Profile Through North Target Area



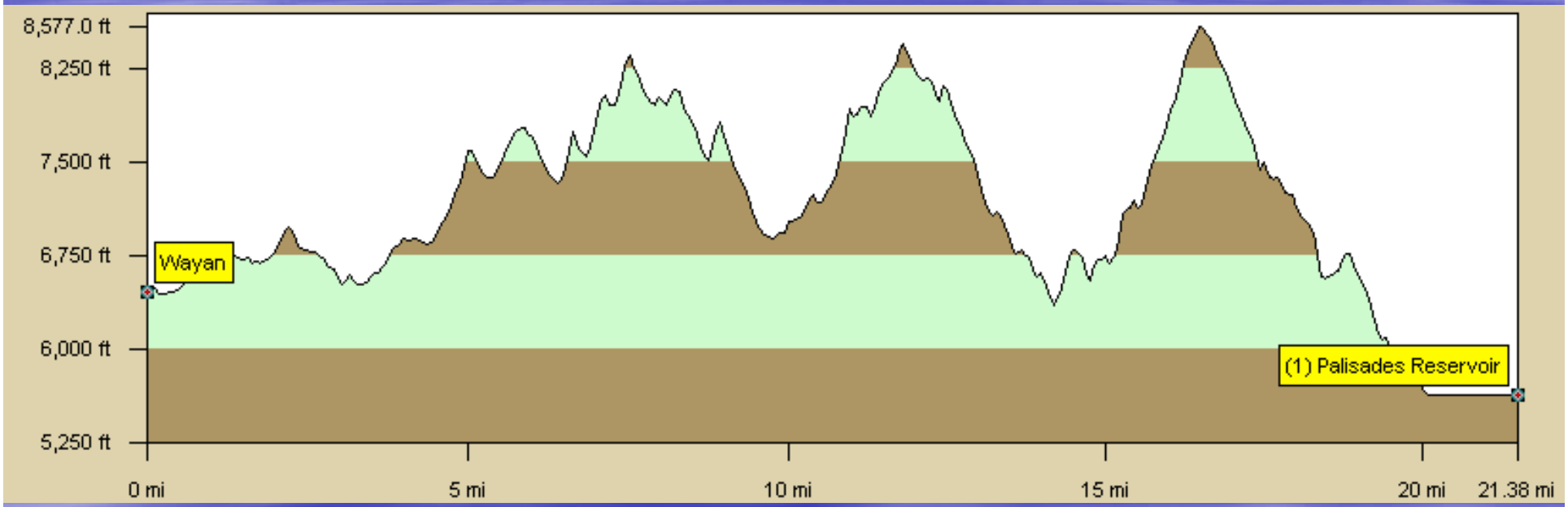
Vertical Profile, North Target Area



Profile Through East Target Area



Vertical Profile, East Target Area



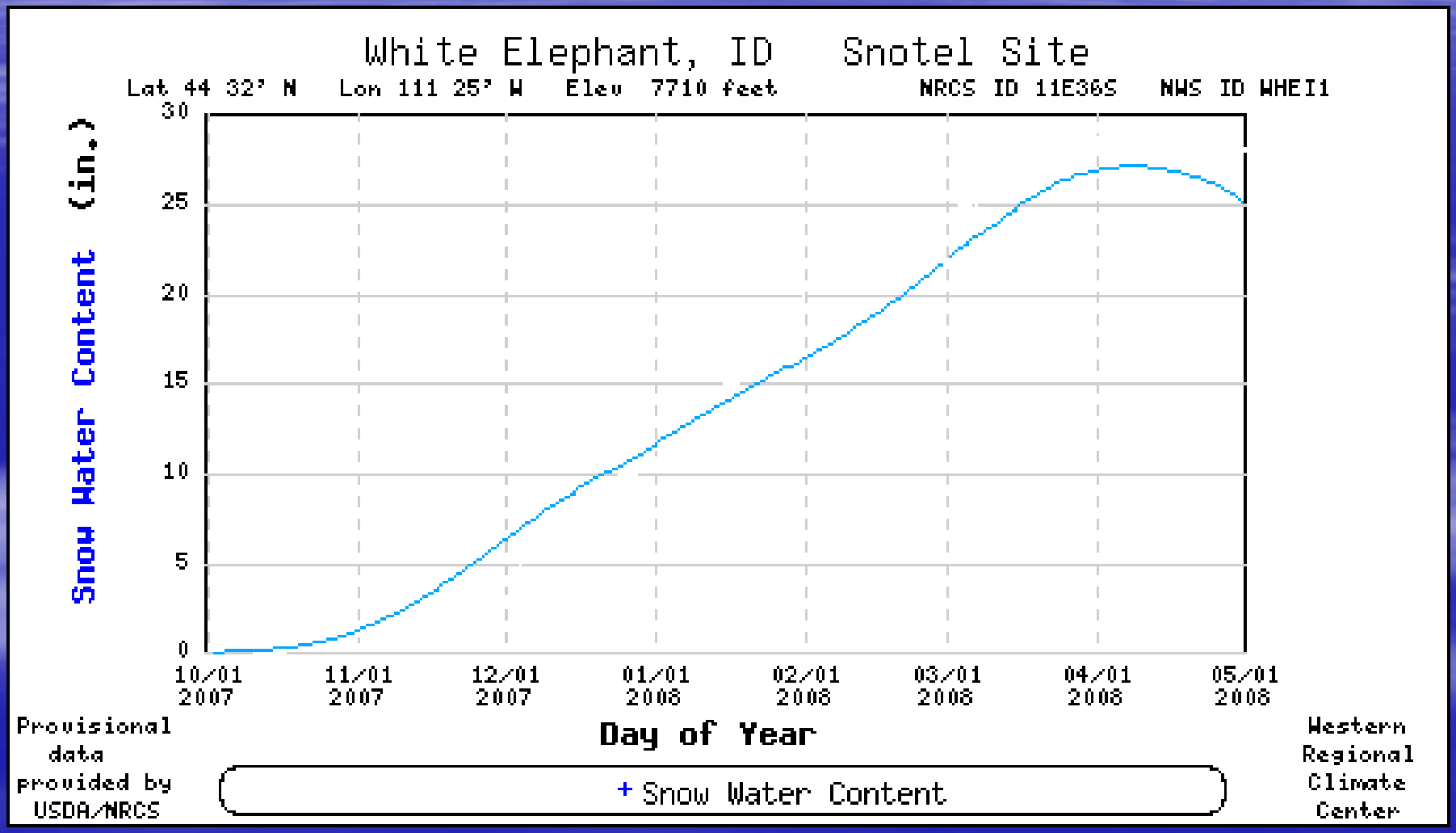
Review and Summary of Prior Studies and Research (Task 1)

- Previous Research Programs in the Intermountain West (Climax I and II, Bridger Range Experiment) Indicate the Potential to Increase Winter Snowfall in the West.
- A Number of Long-Term Operational Winter Cloud Seeding Programs in the West Indicate Apparent Effects of Cloud Seeding in this Range.
- Capability Statements from Several Professional Societies Indicate the Potential to Increase Winter Precipitation in Mountainous Areas by 5 to 15%
- Two Feasibility Studies Conducted Recently for Potential Project Areas in Wyoming Indicate Potential Increases of Approximately 10%.

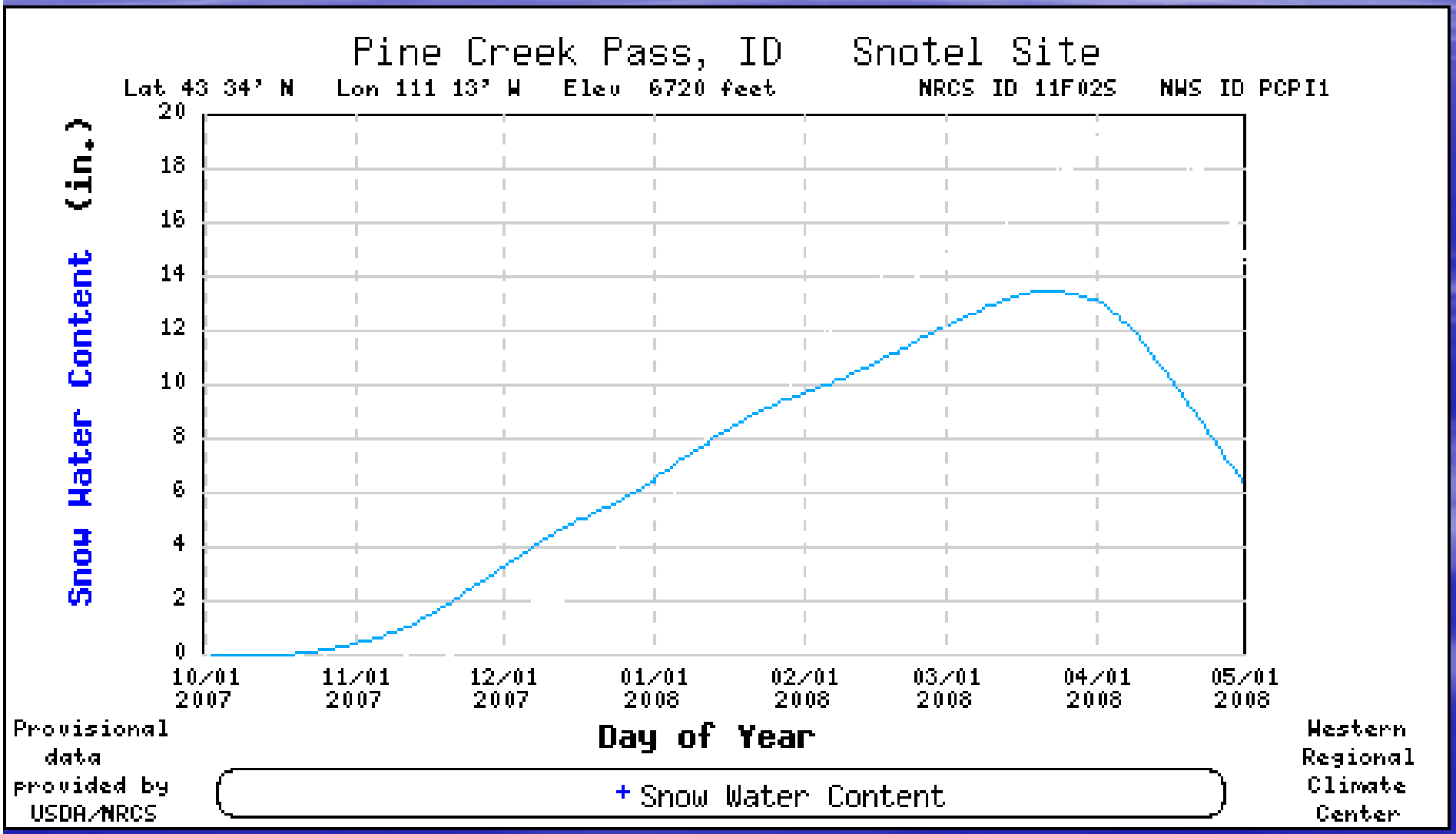
Recent Results From Winter Seeding Programs in Utah

Review and Analysis of Climatology of Target Areas (Task 2)

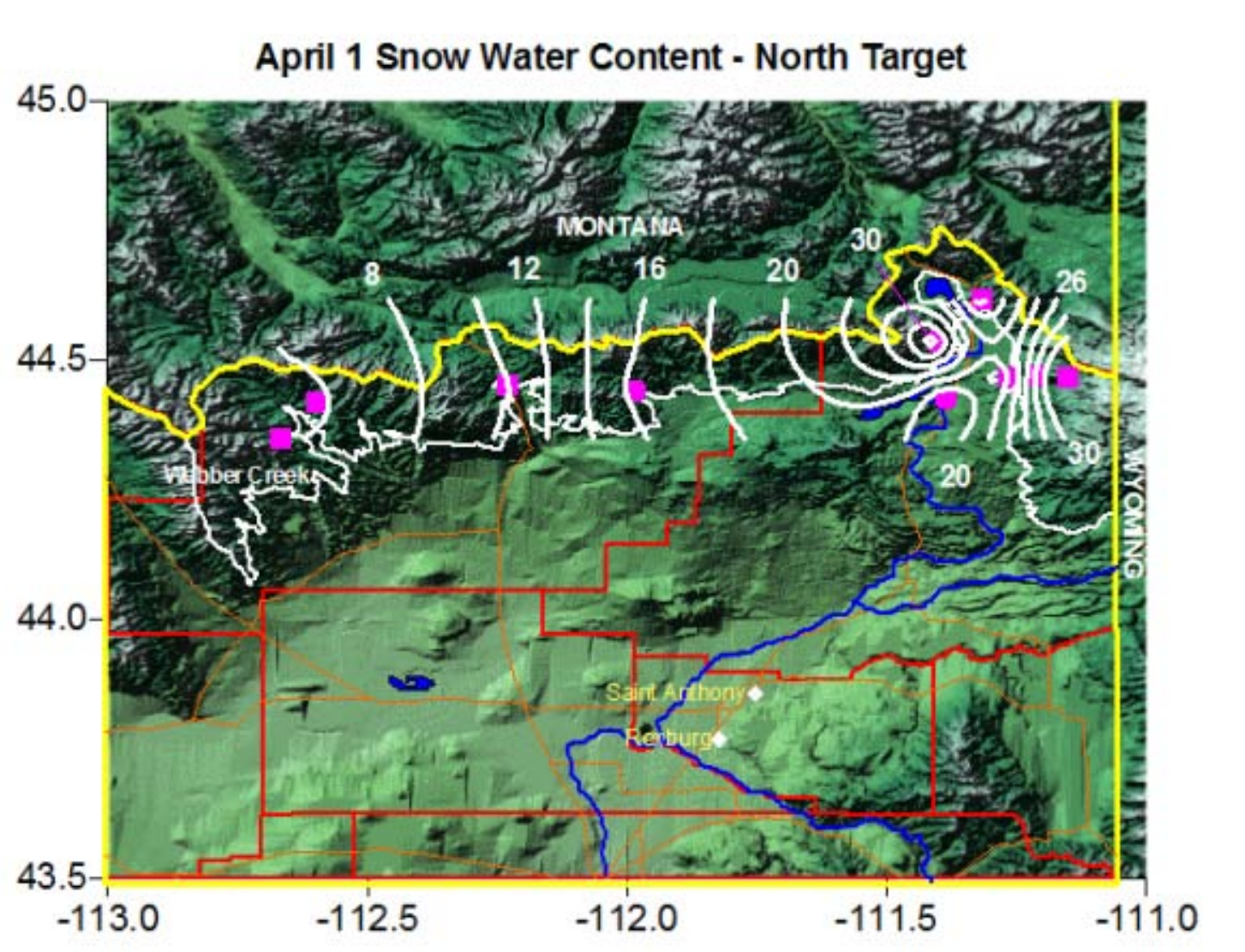
Average Accumulation of Snow Water Content at the NRCS White Elephant Site (North Area)



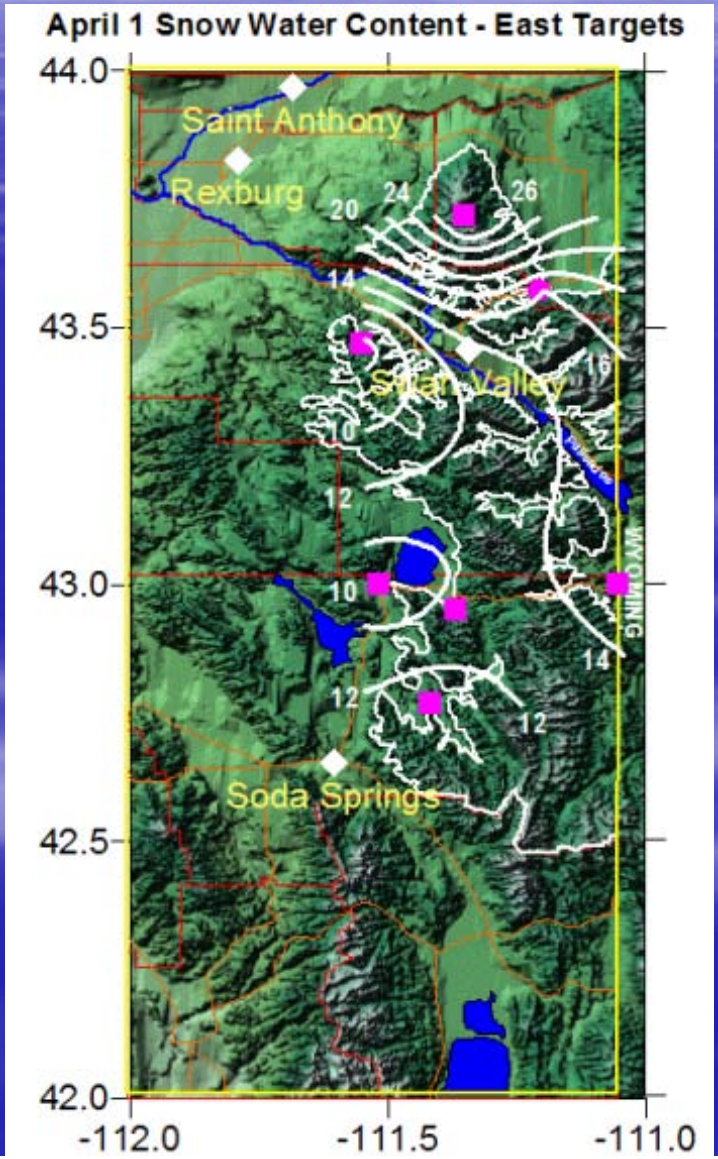
Average Accumulation of Snow Water Content at the NRCS Pine Creek Pass Site (East Area)



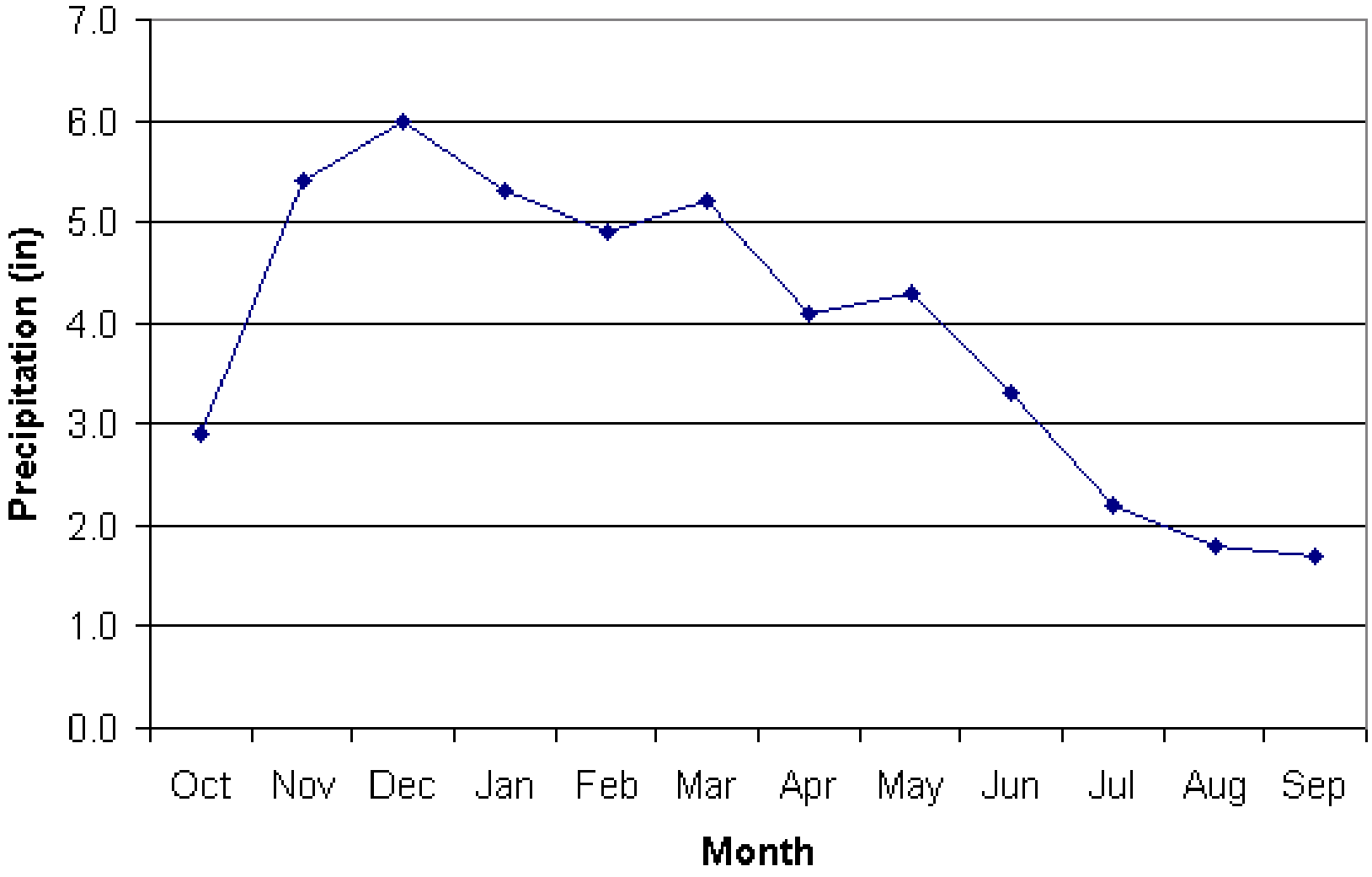
Average April 1st Snow Water Content, North Area



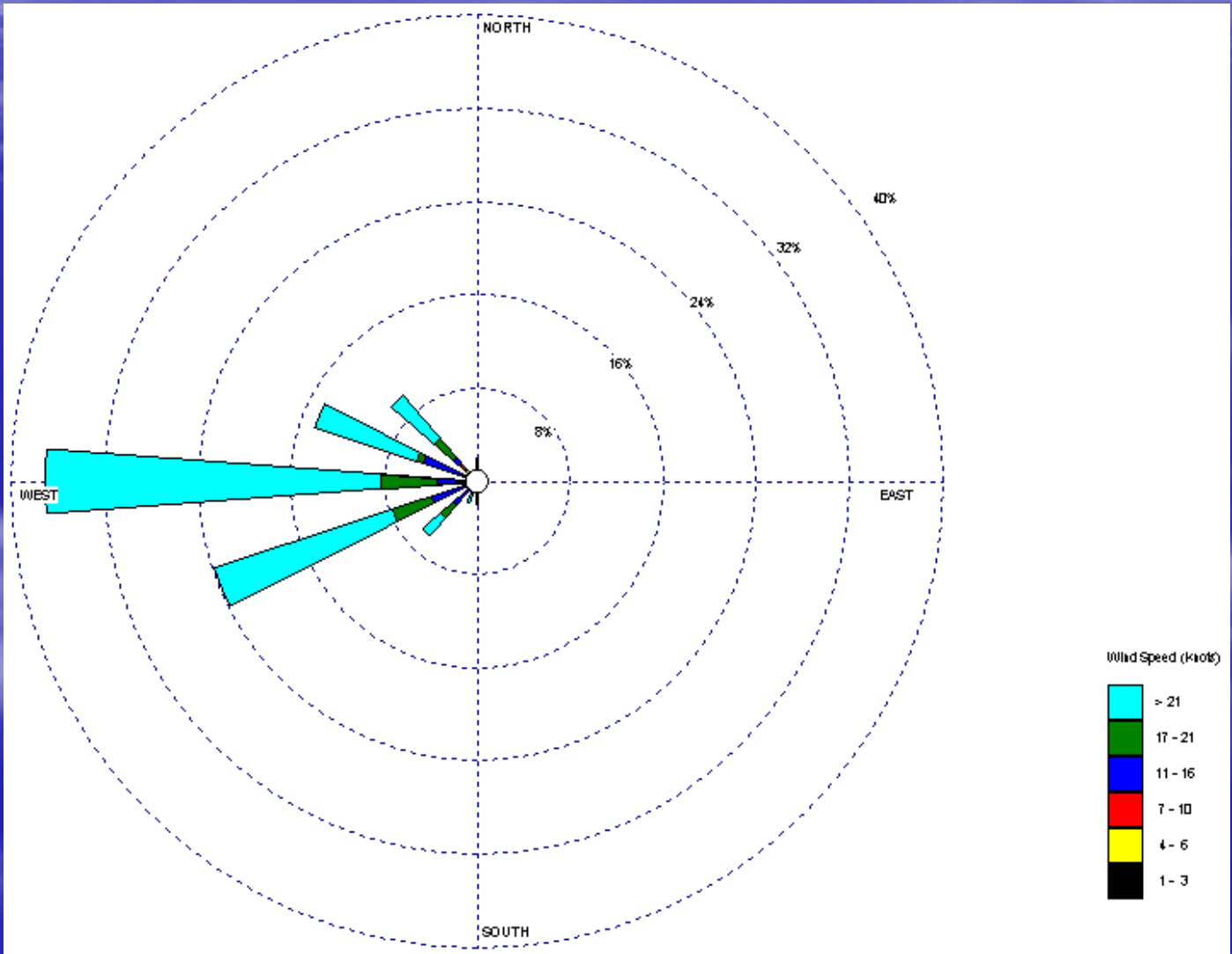
Average April 1st Snow Water Content, East Area



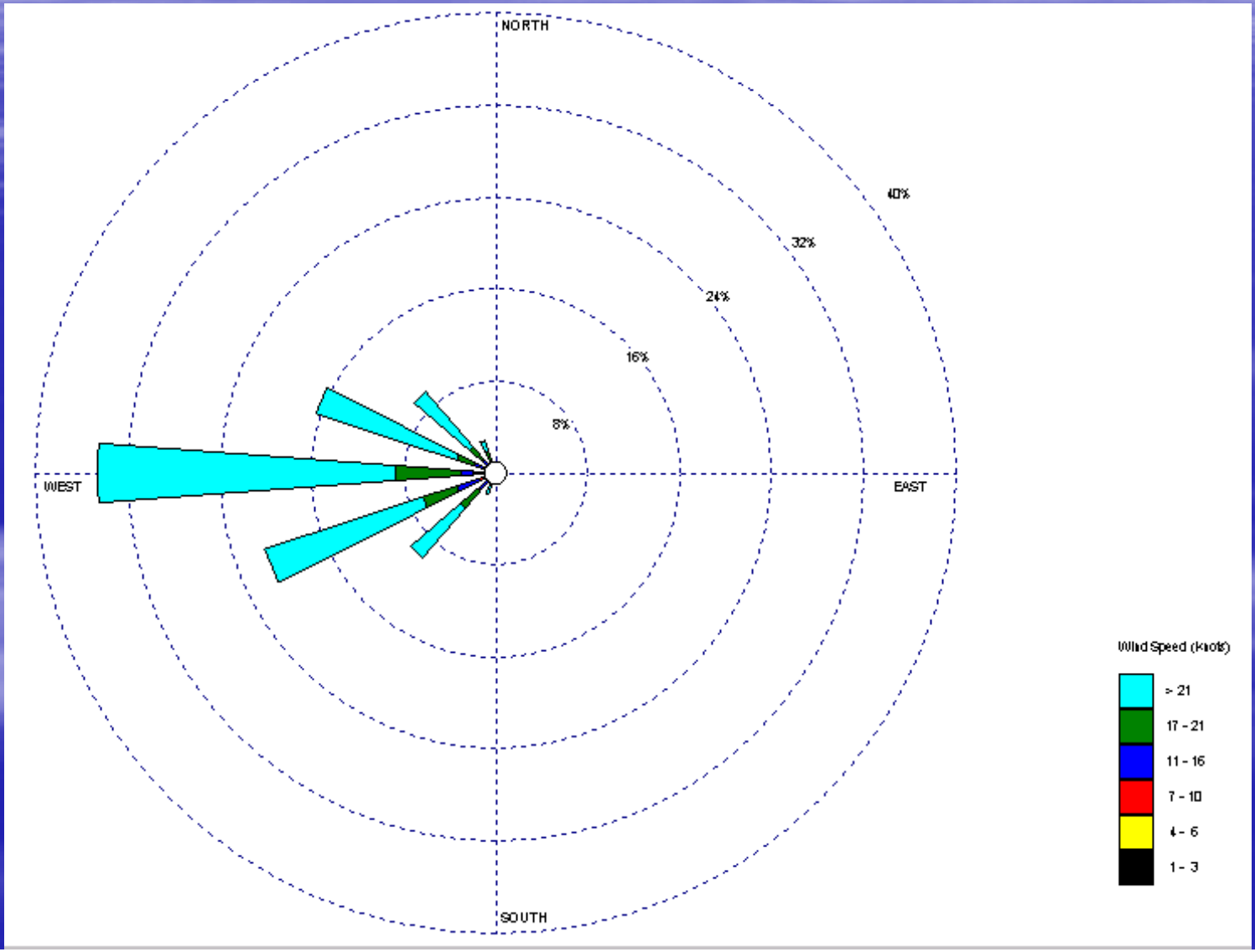
Average Monthly Precipitation at NRCS White Elephant Site (North Area)



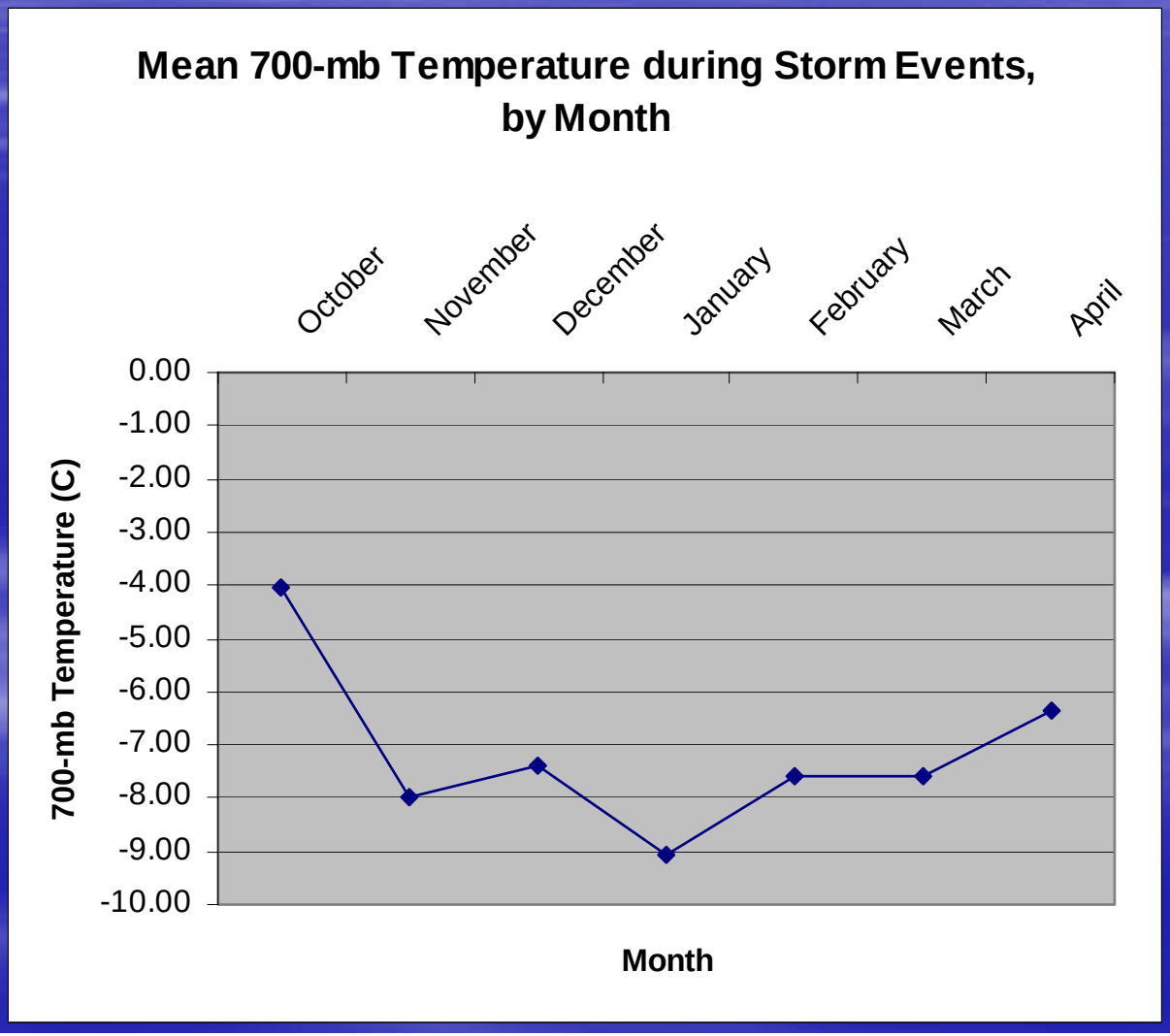
Wind Rose for 700 mb (~10,000 foot level) During Storm Periods, North Area



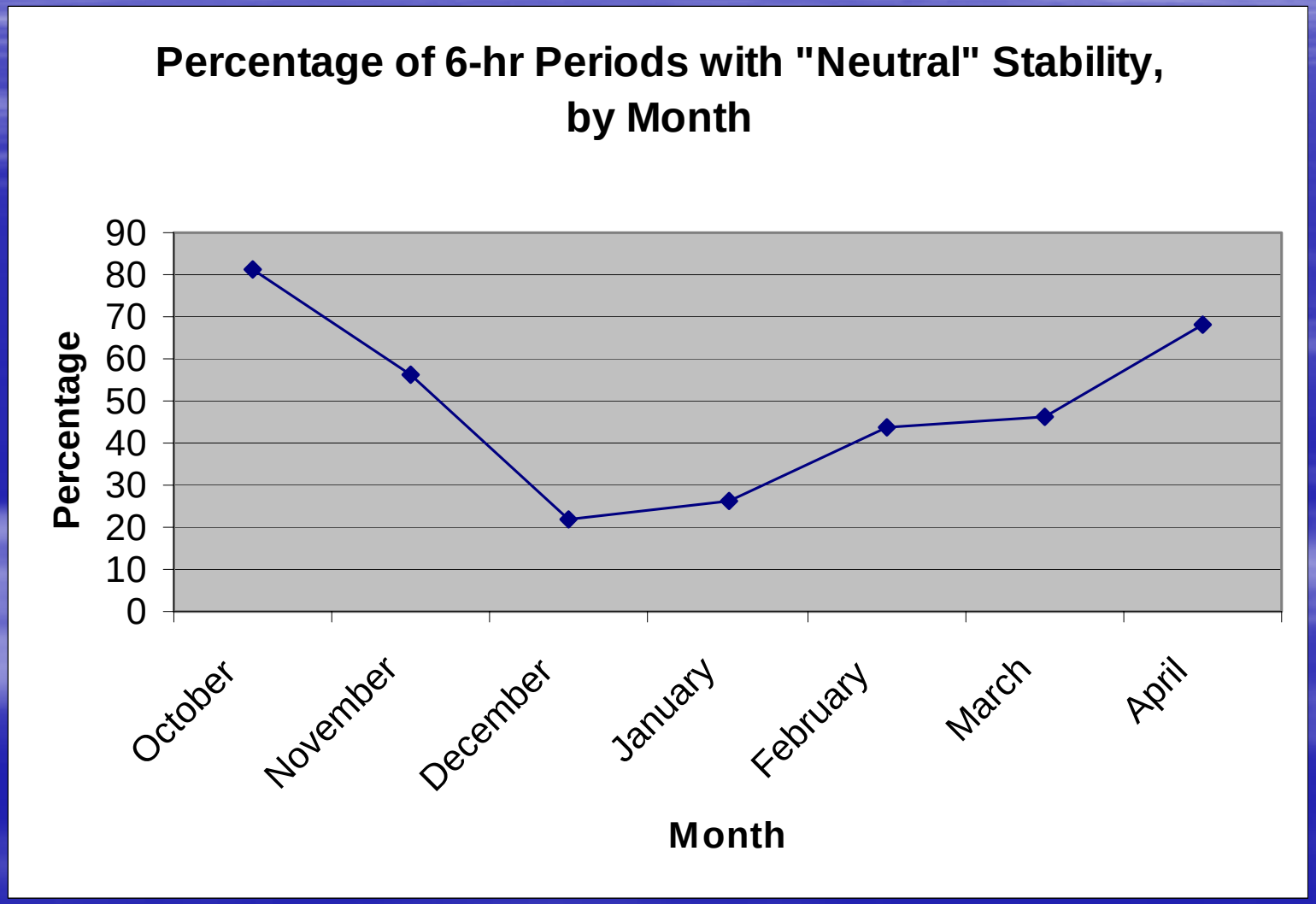
Wind Rose for 700 mb (~10,000 foot level) During Storm Periods, East Area



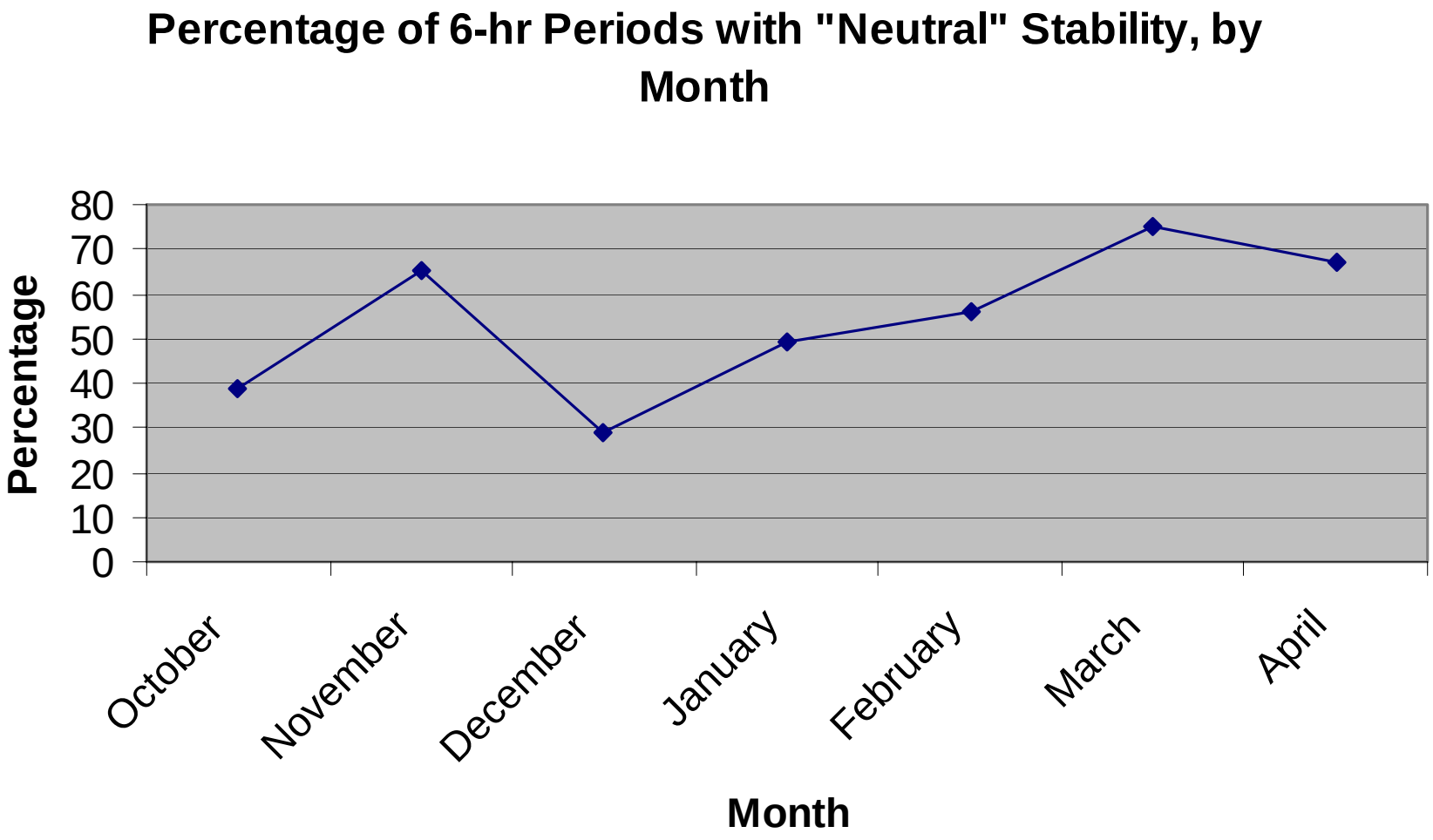
Mean 700 mb Temperature During Storm Events, North Area



Percentage of Six-Hour Storm Events with Neutral Stability by Month, North Area



Percentage of Six-Hour Storm Events with Neutral Stability by Month, East Area



DEVELOPMENT OF A PRELIMINARY PROGRAM DESIGN (Task 3)

Preliminary Design Components

1) Definition of program scope
2) Seeding agent selection
3) Targeting and delivery methods
4) Meteorological data collection and instrumentation
5) Selection and siting of equipment
6) Legal issues
7) Environmental concerns.

Goal of the Cloud Seeding Program

- NAWC proposes the following goal for the ESRBP: The stated goal of the program is to increase winter snow pack in the target areas to provide additional spring and summer streamflow and recharge underground aquifers at a favorable benefit/cost ratio without the creation of any significant negative environmental impacts.

Seeding Agent

Silver Iodide is the most commonly used Seeding Agent and is the agent recommended for this program.

Seeding Modes

The following are the Basic Seeding Modes:

- Ground Based Generators, Manual Operation
- Ground Based Operation, Remote Operation
- Aerial Generation Methods

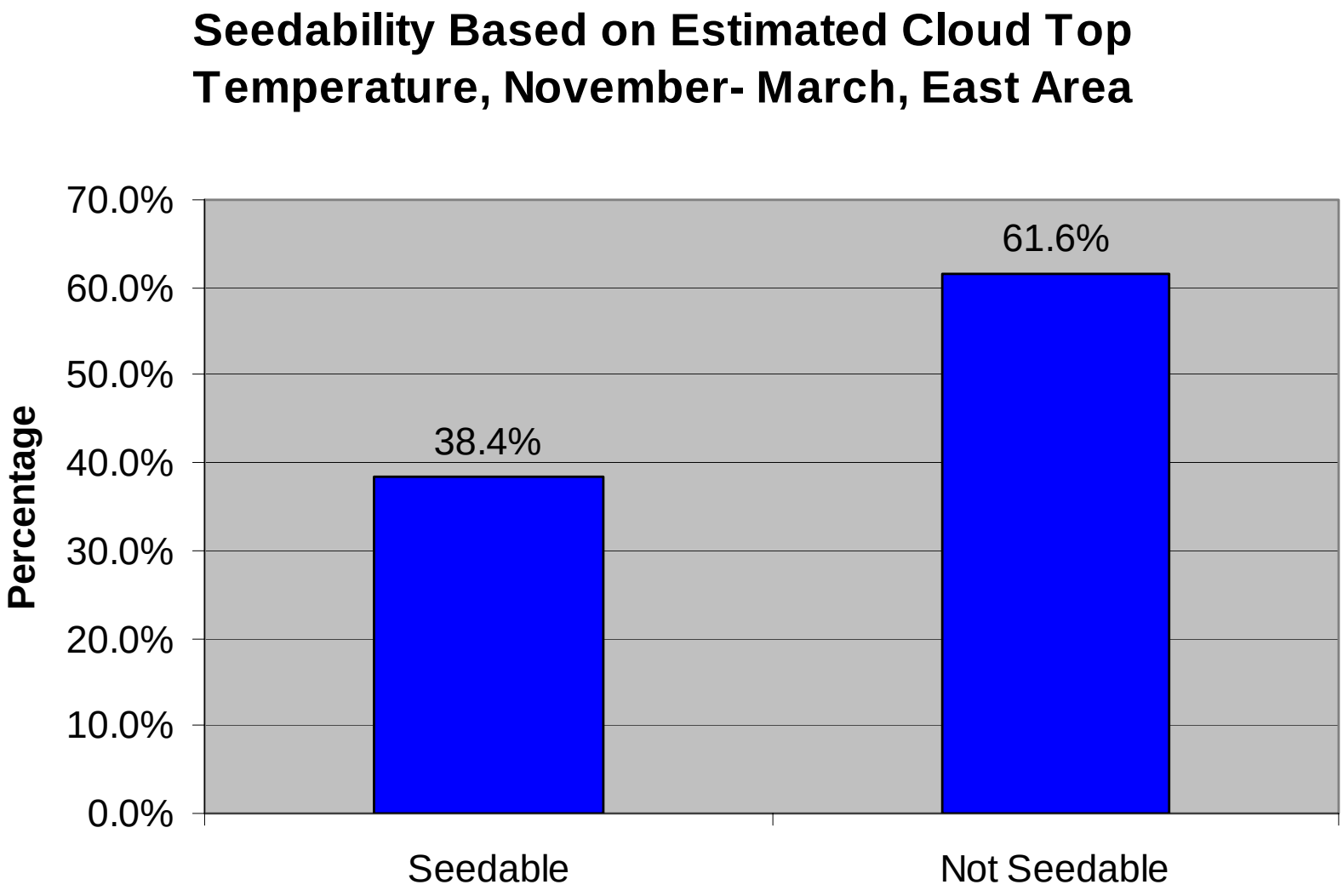
Ground Based, Manually Operated Silver Iodide Cloud Seeding Generator

Remotely Controlled, Ground Based Silver Iodide Generator

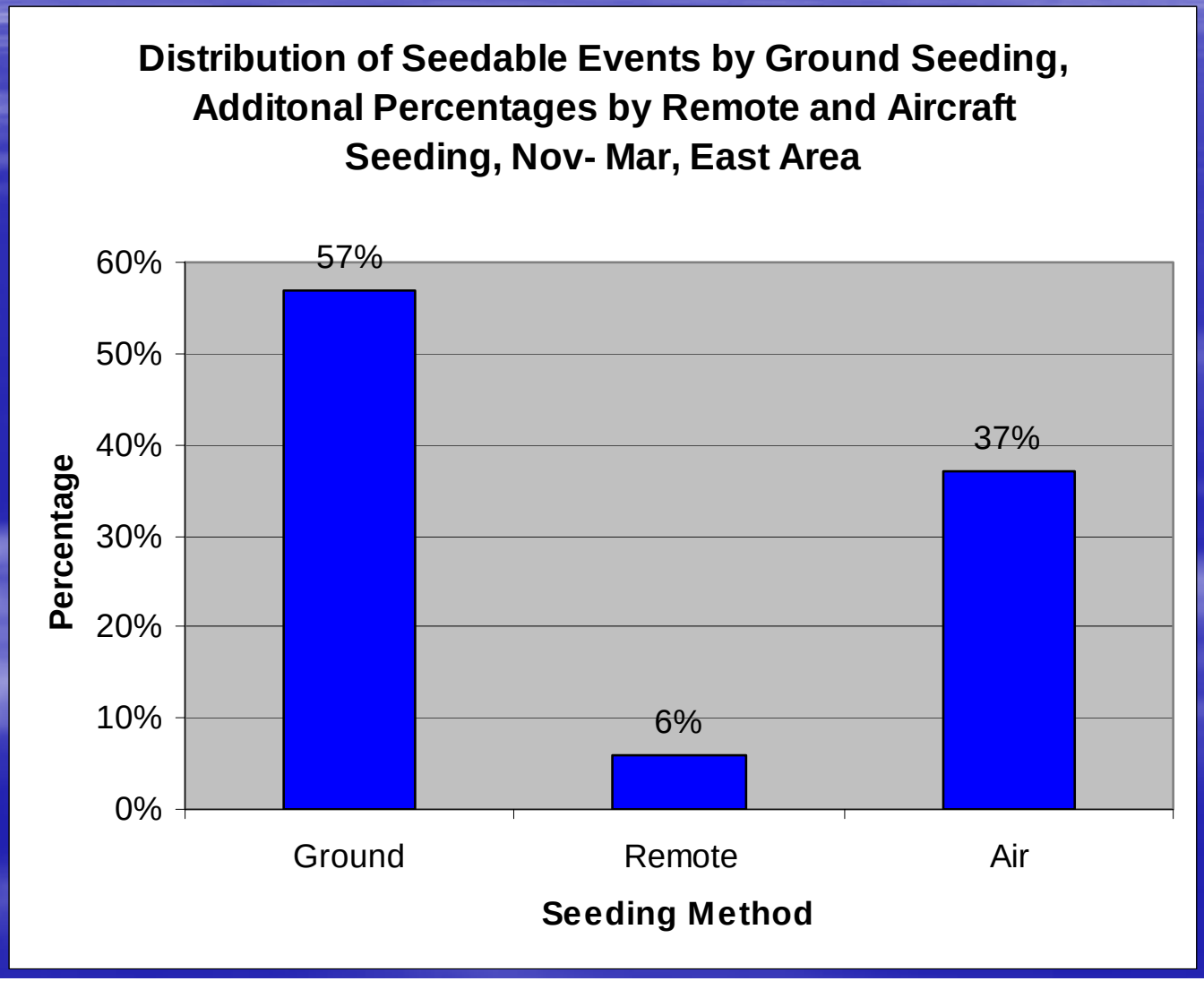
Cessna 340 Seeding Aircraft

Cessna 340 with Silver Iodide Solution Burning Generators and Burn-In-Place Flare Racks

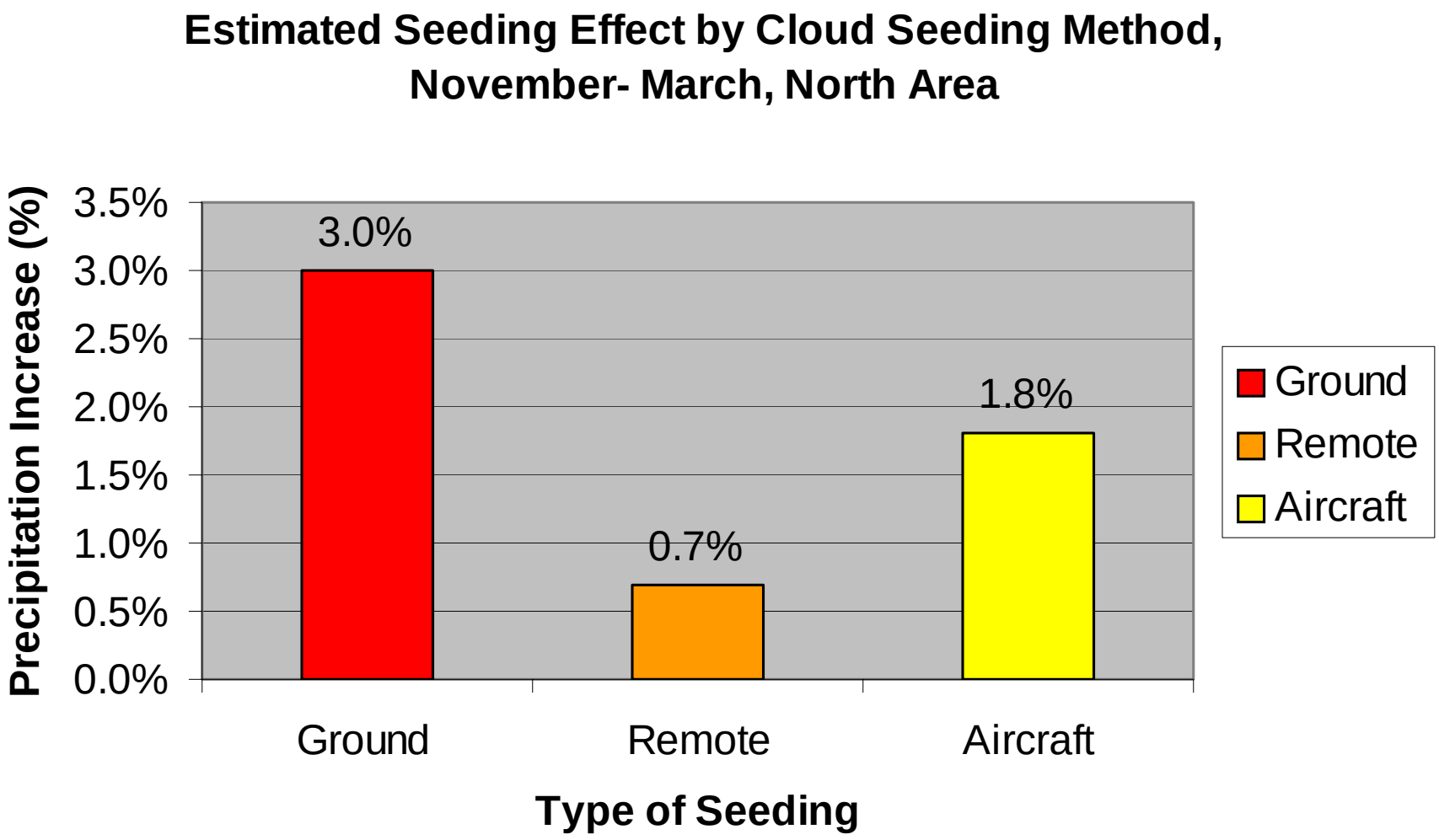
Seedability of 6-Hour Periods in Detailed Analysis Based on Estimated Cloud Top Temperature, East Area



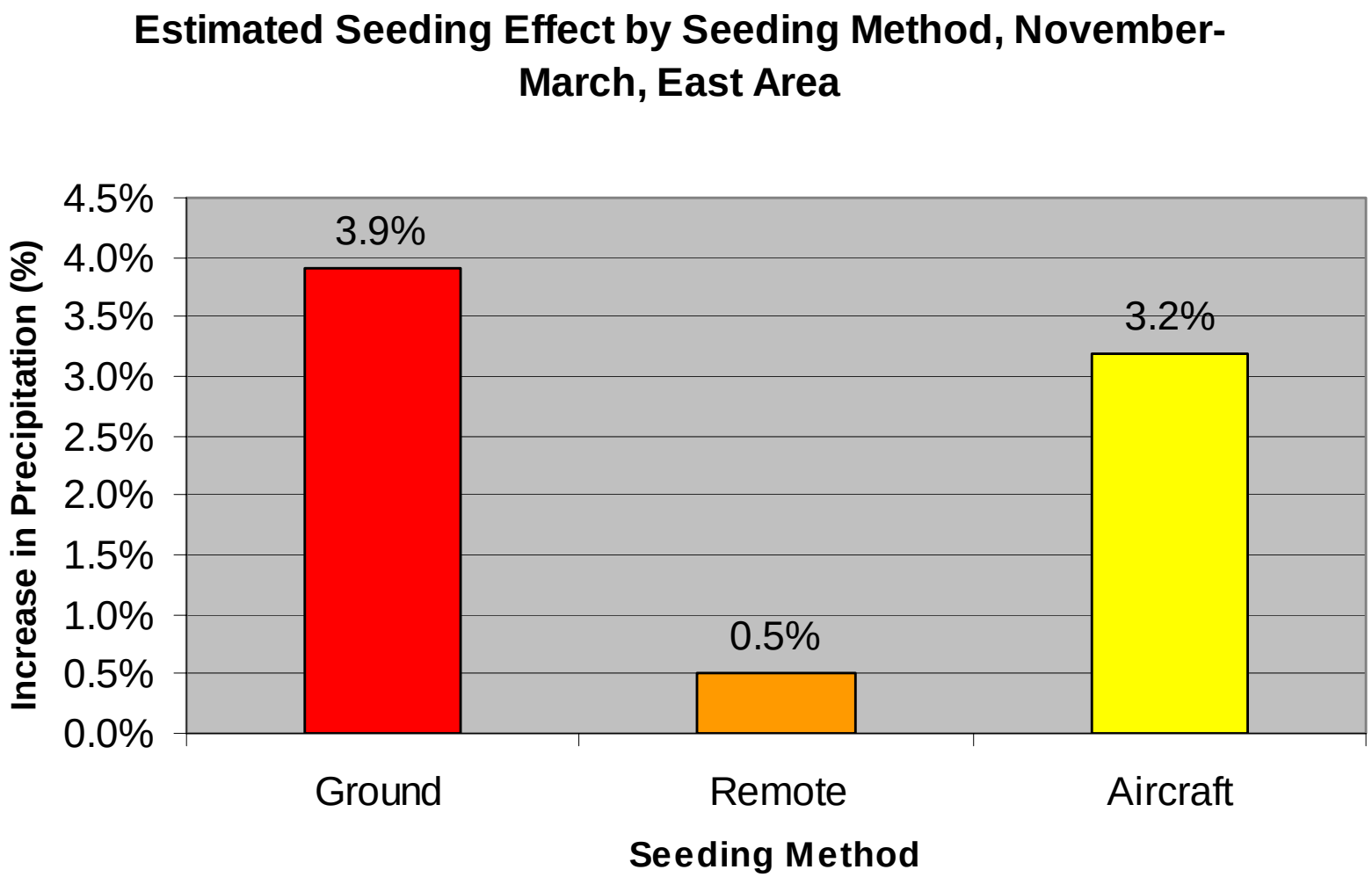
Estimates of Percentage Increases for Seedable Cases Partitioned by Seeding Mode, East Area



Estimates of Percentage Increases in November – March Precipitation for Seedable Cases Partitioned by Seeding Mode, North Area



Estimates of Percentage Increases in November – March Precipitation for Seedable Cases Portioned by Seeding Mode, East Area



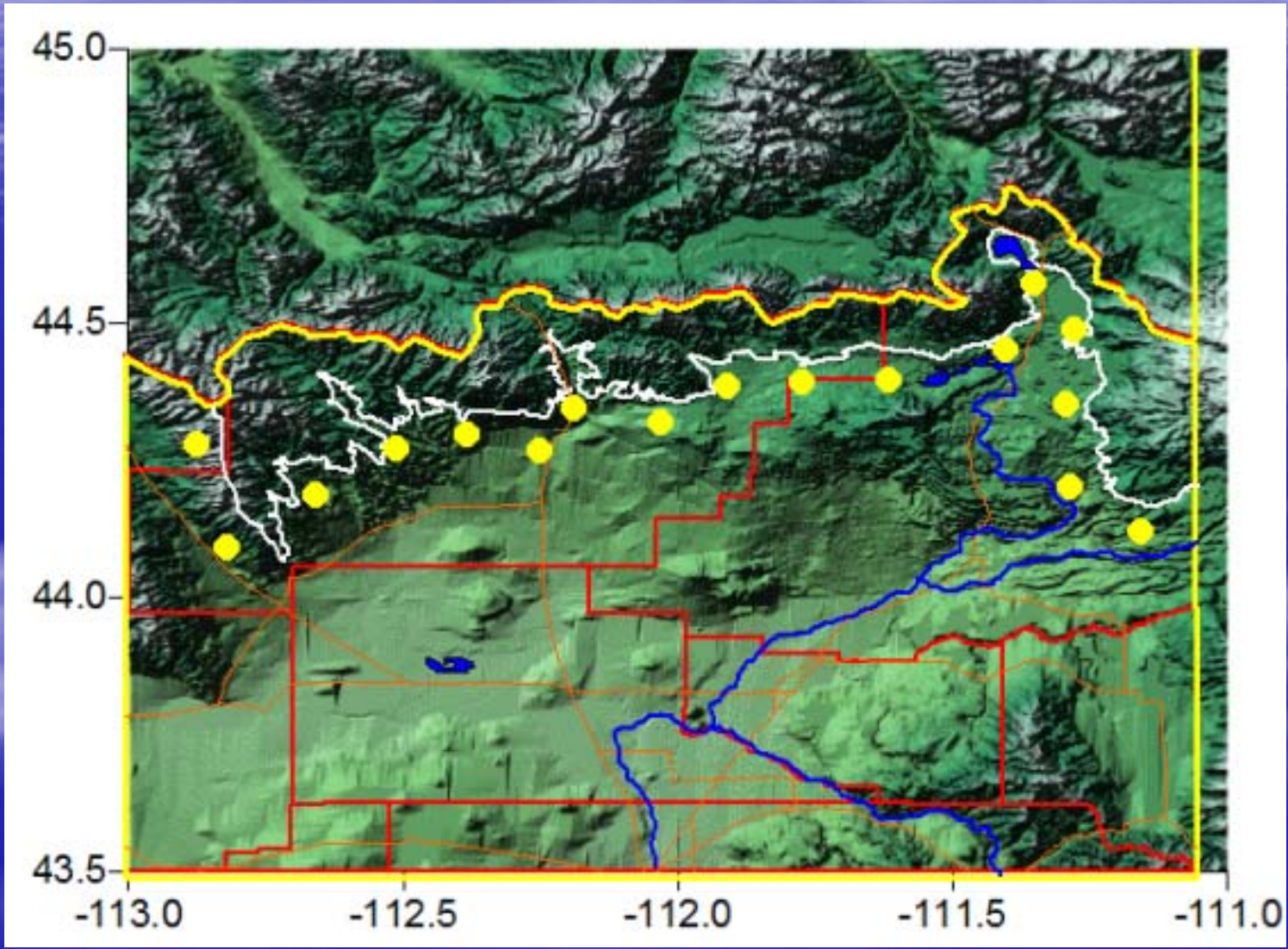
Conclusions on Seeding Modes and Potential Increases in Precipitation

- A program could be run only using manually operated ground based generators to potentially achieve a 3.0 % average increase in the North area and a 3.9 % average increase in the East area. This might be considered as a “core” seeding program which would be the least costly type of operation.

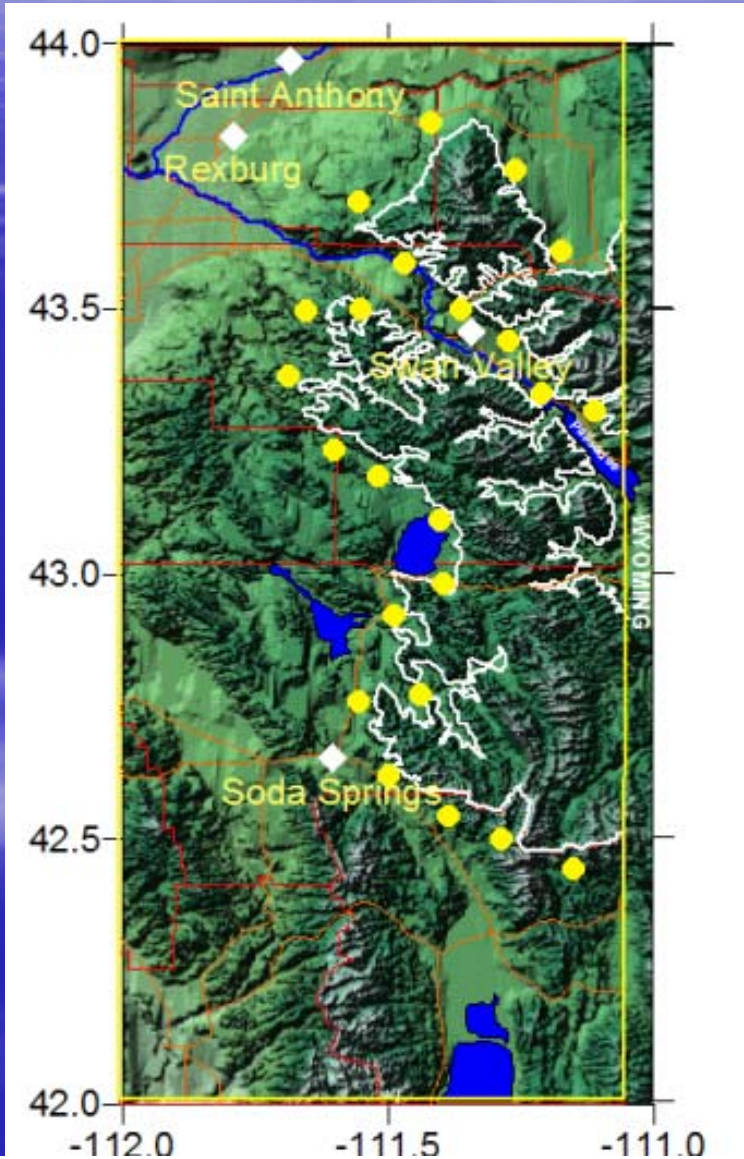
- Based upon the percentages of potential increases, it does not appear that the use of remotely controlled, ground-based generators is warranted, at least from a benefit/cost perspective

- To optimize seeding effects, a program utilizing manually operated ground generators plus a seeding aircraft could potentially achieve a 5.5 % increase in the North area and a 7.6 % increase in the East area. The aircraft could seed in conditions where remotely controlled ground generators might be used, so the remotely controlled estimated increases have been included in the aircraft estimates.

Approximate Locations of Manually Operated Ground-Based Generators, North Area



Approximate Locations of Manually Operated Ground-Based Generators, East Area



Meteorological Data Collection and Instrumentation

There are three primary uses of or justifications for the addition of meteorological measurements or instrumentation:

1) Such additions will assist in better targeting of the seeding material,
2) Such additions will provide better real-time recognition of seeding opportunities, and
3) Such additions will provide the means to help evaluate the effectiveness of the seeding operations.

Recommended Data Collection Approach

NAWC proposes that a phased data collection approach be adopted in the performance of this program. The goal will be to make critical observations early in the history of the program, which may later be discontinued or replaced with more basic measurement or prediction approaches.

For example, one of the primary concerns regarding the conduct of a winter orographic cloud seeding program in a new area is the frequency, magnitude and location of supercooled liquid water upwind and over the barriers in question. We propose that a ground based icing rate meter be operated in each of the target areas

A microwave radiometer could provide vertically integrated samples of the water content of the atmosphere from the surface to the top of the atmosphere but these radiometers are more costly than the icing rate meters. A microwave radiometer could be operated for one or two winters in association with ground based icing rate meters to determine how the degree of correlation between the two observational techniques.

We also propose that program specific rawinsonde (weather balloon) observations be taken during storm periods during the first winter season of the program.

Summary of Recommended Preliminary Design

- The stated goal of the program is to increase winter snowpack in the target areas to provide additional spring and summer streamflow and recharge under-ground aquifers at a favorable benefit/cost ratio, without the creation of any significant negative environmental impacts.
- The target area will be those areas in Bonneville, Clark, Fremont and Madison Counties that lie above 6,500 feet (2.0 km), which are tributaries to the Snake River.
- The primary operational period will be November through March.
- Silver iodide will be the seeding agent
- A “core program” of lower elevation ground based generators is recommended, This core program could be supplemented by a seeding aircraft equipped with acetone/silver iodide generators if the estimated benefits constitute an acceptable multiple of the estimated costs to utilize this additional seeding mode.
- Evaluations of the effectiveness of the cloud seeding program would be based upon historical target and control techniques
- Qualified/experienced meteorologists should direct the seeding operations.

Establishment of Operational Criteria (Task 4)

- Opportunity Recognition Criteria
- Communications of Seeding Decisions
- Seeding Suspensions
- Communications of Seeding Activities

Seeding Suspension Criteria

1. Excess snowpack accumulation
2. Rain and/or snowmelt-induced winter flooding
3. Severe weather
4. Avalanches

Development of Monitoring and Evaluation Methodology (Task 5)

- Target/Control Evaluations
- Randomization
- Silver in Snow Evaluations
- Computer Simulations

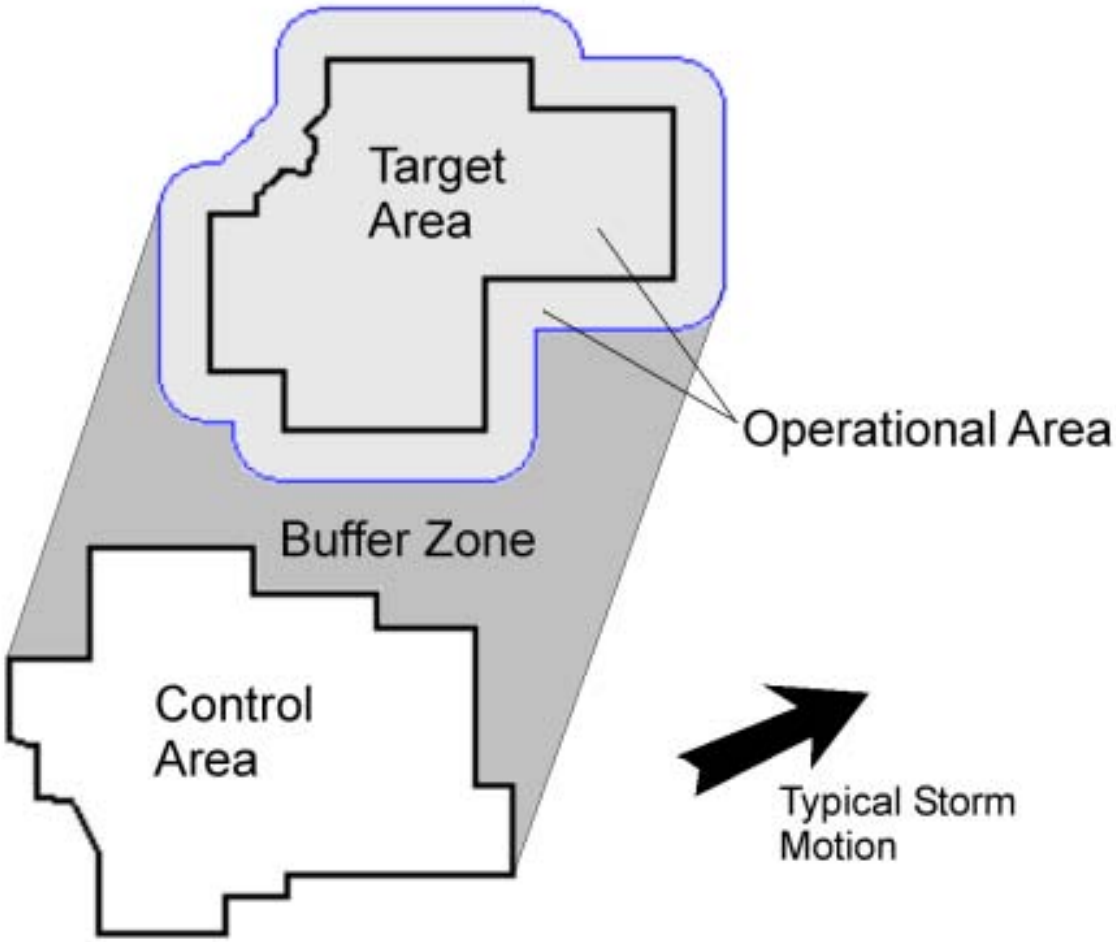
Review of Environmental and Legal Aspects (Task 6)

- Downwind Effects
- Toxicity of Seeding Agents
- Avalanche Considerations
- Snow Removal
- Delay of Snowmelt
- General Statements on the Potential Environmental Impacts of Winter Cloud Seeding
- Legal Implications

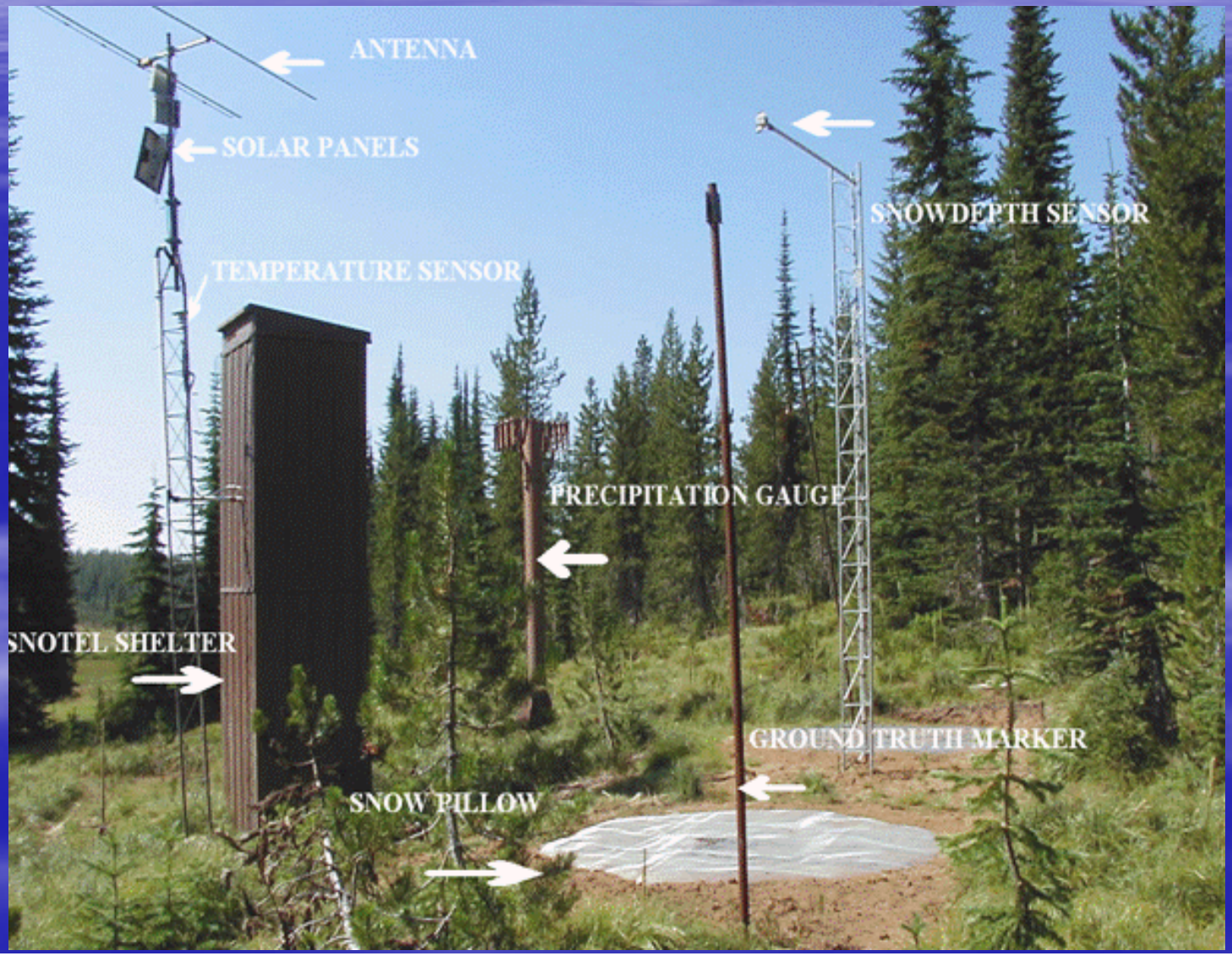
Statistical Analysis of 2007-2008 Winter Cloud Seeding Project in Eastern Idaho (Task 10)

Utilized the Historical Target/Control Evaluation Approach to Consider Increases in November-March Precipitation and April 1st Snow water Contents

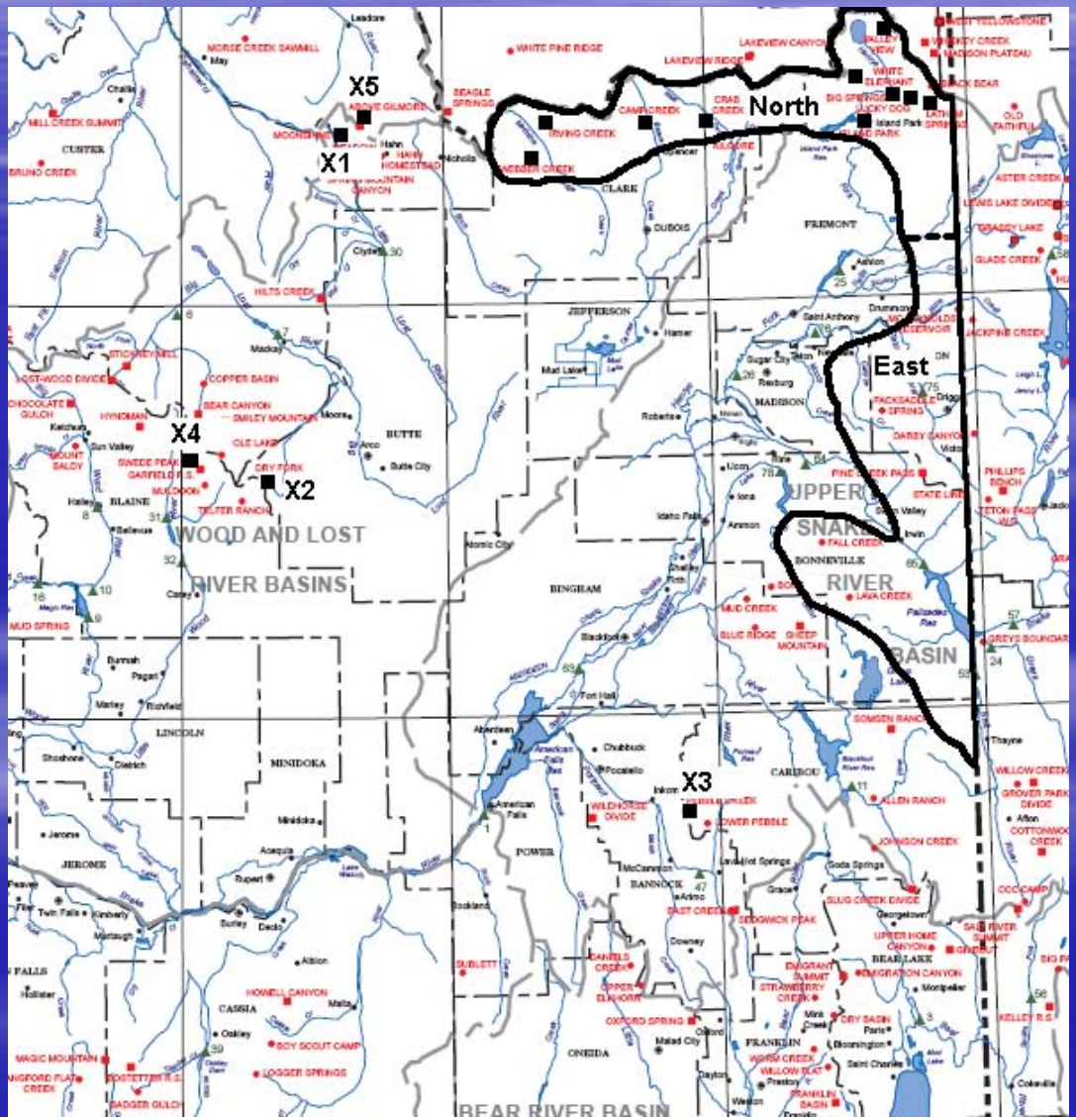
CONCEPTUAL DIAGRAM OF THE RELATIONSHIP BETWEEN TARGET AND CONTROL AREAS



TYPICAL NRCS SNOTEL SITE



Map with final snowpack evaluation sites for the North target area



TARGET/CONTROL REGRESSION EQUATIONS

North Target – April 1st Snowpack:

Control (X)	Target (Y)
Moonshine SNOTEL (X1)	Crab Creek SNOTEL
Dry Fork snowcourse (X2)	Island Park SNOTEL
Pebble Creek snowcourse (X3)	White Elephant SNOTEL
Swede Peak SNOTEL (X4)	Lucky Dog snowcourse
Above Gilmore snowcourse (X5)	Big Springs snowcourse
	Valley View snowcourse
	Camp Creek snowcourse
	Irving Creek snowcourse
	Webber Creek snowcourse
	Latham Springs snowcourse

Linear: $Y = 1.05(X) + 3.4 \quad (r = 0.95)$

Multiple Linear: $Y = 0.54(X1) + 0.10(X2) + 0.19(X3) + 0.19(X4) + 0.03(X5) + 3.6 \quad (r = 0.96)$

North Target, April 1st Snow Water Content, Linear Regression Equation Results

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
1997	18.22	25.02	22.55	1.11	2.47
1998	11.44	15.16	15.43	0.98	-0.27
1999	15.58	20.15	19.77	1.02	0.38
2000	10.96	16.21	14.93	1.09	1.28
2001	5.54	8.78	9.24	0.95	-0.46
2002	9.88	14.90	13.79	1.08	1.11
2004	8.18	15.22	12.01	1.27	3.21
2006	18.02	19.94	22.34	0.89	-2.40
2007	5.96	9.57	9.68	0.99	-0.11
2008	**13.7**	**18.7**	**17.80**	**1.05**	**0.93**
Mean*	11.7	16.4	15.8	1.04	0.62

East Target, April 1st Snow Water Content, Linear Regression Equation

YEAR	XOBS	YOBS	YCALC	RATIO	EXCESS
2002	10.58	12.47	13.48	0.92	-1.01
2003	6.35	12.87	9.06	1.42	3.81
2004	9.13	12.47	11.96	1.04	0.50
2005	8.65	11.67	11.47	1.02	0.20
2008	**14.0**	**17.5**	**17.09**	**1.03**	**0.44**
Mean	9.7	13.4	12.6	1.06	0.79

PRELIMINARY ESTIMATED AVERAGE INCREASES IN MARCH – JULY STREAMFLOW ON WILLOW CREEK BELOW TEX CREEK NEAR RIRE, IDAHO

- APPROACH: USE ESTIMATED INCREASES IN APRIL 1ST SNOW WATER CONTENT FOR EAST AREA BY SEEDING MODE BASED ON ANALYSIS FROM TASK 5. RELATE APRIL 1ST NRCS SNOW MEASUREMENT CONTENTS IN THE AREA TO MARCH - JULY STREAMFLOW THROUGH A REGRESSION EQUATION. ESTABLISH AN AVERAGE RUNOFF VALUE IN TERMS OF APRIL 1ST SNOW WATER CONTENT. THEN INCREASE SNOW WATER CONTENT VALUE TO SEE IMPACT ON STREAMFLOW.

- RESULTS: AN INCREASE OF 3.9% IN APRIL 1ST SNOW WATER CONTENT CALCULATED TO BE DUE TO GROUND BASED SEEDING RESULTED IN AN ESTIMATED 8.1% INCREASE IN STREAMFLOW OR 4937 ACRE FEET.

- RESULTS: AN INCREASE OF 7.6% IN APRIL 1ST SNOW WATER CONTENT CALCULATED TO BE DUE TO GROUND BASED AND AIRBORNE SEEDING RESULTED IN AN ESTIMATED 15.7% INCREASE IN STREAMFLOW OR 9622 ACRE FEET.

Estimates of Streamflow Increases for the North and East Areas

NAWC is Currently Working with IWRB personnel to develop estimates of Increases in Streamflow for the North and East Areas. Lack of Long-term Historical, Unregulated Streamflow Records is Complicating this effort.

Hypothetical Example of the Impact of an Increase of One Inch of April 1st Snow Water Content

Assumptions:

Size of Target Area - 1000 square miles

Average Increase in April 1st Snow Water Content – One inch

1000 Sq.mi. X 1inch/12 inches per foot X 640 acre/sq. mi.+

= 53,333 acre feet

Summary

- The Study is Nearing Completion.
- It Appears the Conduct of a Winter Operational Cloud Seeding Program is Feasible for These Areas

Questions??

North American Weather Consultants Web Site:

www.nawcinc.com