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Memorandum

PAP

HYDRAULICS BRANCH
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Memorandum

Denver, Colorado
DATE: June 7, 1972

TO : Chief, Division of Atmospheric Water Resources Management

THROUGH: Chief, Division of General Research

FROM : Chief, Hydraulics Branch

SUBJECT : Stratified liquid model

In your February 29, 1972 memorandum, you requested an expanded report on the stratified liquid model study to include the following:

1. Establishment of similarity hypothesis regarding 2:1 scale height exaggeration with respect to actual terrain roughness

2. Establishment of capability to simulate desired density distribution at critical locations on terrain model

3. Establishment of similarity hypothesis with respect to dam effect of terrain model as a whole

This memorandum is intended to report on our investigation of these questions, to summarize significant findings of our original studies, and to outline proposed future studies and their required funding.

Similarity Hypothesis Regarding Vertical Distortion

For a model to truly represent actual conditions, it must be geometrically, kinematically, and dynamically similar to the prototype. If the model deviates from the prototype in any one of the three areas of similitude, then more care must be taken to interpret the model results. However, if the deviation is too large, the model no longer represents the prototype and no amount of interpretation will yield the correct results.

The kinematic and dynamic similarity criteria for modeling the mean motion of the atmosphere were investigated by Yih 1/. The criteria are

1/ Yih, C., Dynamics of Nonhomogeneous Fluids, MacMillan Co., N.Y., 1965

a. The upstream distribution of potential density in the compressible flow is identical with the upstream distribution of density in the incompressible flow.

b. The wind profiles are identical, or nearly so.

The design of the liquid simulation model was based on these studies. Fortunately, these two similarity conditions can be met with reasonable accuracy in the model. The range of flexibility in establishing various density distributions in the model is discussed under the next heading.

These conditions might be considered generally as those necessary for similarity based on a Richardson number. Reynolds similitude refers to the fluid turbulence. No effort was made to achieve Reynolds similarity. Therefore, flow phenomena related to turbulence such as diffusivity and spreading of a plume cannot be determined from the model.

Geometric similitude could not be maintained in the model because commercially available maps were used. These maps had a 2:1 vertical distortion in the scale. The original plan to study the distortion was to investigate the effects on the model. The flow over several undistorted simple geometric shapes was to be compared with the flow over equivalent distorted shapes. This method, while frequently used in laboratory practice, is deficient since the question of extrapolating the data to prototype scales is not definitely resolved.

Another frequently used method to investigate the effects of vertical exaggeration is to calibrate the model using prototype results. For instance, river models are often distorted as much as 5:1. The bed roughness is varied until an historic event can be duplicated. This method while not the most scientific is certainly the most practical. The main deficiency of this method is its susceptibility to the vagaries of field measurements. This was the method chosen to determine if the 2:1 vertical exaggeration of the map was so large that an accurate representation of field conditions was impossible.

The area chosen for the comparison was the Climax-Leadville area where field investigations had been conducted. The criterion for evaluation was the motion of the mean axis of the dye plume from stations located at Mintern, Red Cliff, and Camp Hale. The comparison of the model with the field measurements resulted in the following conclusions:

a. The mean motion of the dye axis in the model and the silver iodide plume in the prototype were similar.

b. After a model time corresponding with approximately 9 months' real time, dye still lingered in the valleys. Field studies indicated a high background count after 1 year. At that time, it was felt that silver iodide caught on pine needles was the cause of the high count.

c. Valley velocities measured in the model varied between 2.5 and 7.0 meters/sec. Equivalent field measurements varied between 2.0 and 6.0 meters/sec.

d. Some motion of dye into the transverse valleys was noted in the model. Evidence of similar movement was noted in the field.

Based on these observations, we feel that the liquid model satisfactorily simulates conditions observed in the field and that the 2:1 vertical exaggeration is not large enough to make the model results invalid.

Capability to Simulate Desired Density Distribution

The simulation of the atmosphere depends very strongly on the ability to achieve a distribution of density in the model which is identical to the distribution of potential density in the atmosphere. To study the flexibility in the model, two approaches were taken. The first was to try to simulate the distribution actually observed in the field. The second was to compare the distributions achieved with several mathematical descriptions of the atmosphere.

The first approach consisted of filling the model half full with fresh water. This was allowed to come to room temperature. Then, the filling of the model was completed by the addition of the salt solution underneath the fresh water layer. Previous computations, assuming a molecular diffusion process caused mixing, were used to predict a given gradient at any later time. An attempt was made to reproduce the Camp Hale radio sonde data for two observed cases. These were: (1) storms with temperature inversions, and (2) storms without temperature inversions. For the first case, the distribution in the model was close to but not identical with the atmospheric distribution above the 4500 meter level. This distribution corresponded with a model mixing time of approximately 5 hours. After 25 hours, the distribution should have simulated the Camp Hale without inversions, case 2. Again, the distribution was close below 4500 meters but deviated above that elevation, Figure 1.

The results indicate that accurate distributions could have been achieved after approximately 8 hours and 30 hours respectively. Two reasons for the error in the predictor model are probable. These are: (1) the prediction model does not account for mixing which occurs near the map surface, and (2) the prediction model assumes that the density gradient upstream of the physical model is truncated at the elevation of the top of the physical model. Actually, some of the denser fluid from below the map surface flows up onto the map.

Comparisons with conceptual models of the atmosphere were generally poor, Figure 2. The slope of the distribution in the model for the case without inversions was approximately parallel with the conceptual models. However, below 4500 meters the comparison was very poor. The difference can probably be explained by the fact that the conceptual models do not properly account for mixing in the lower layers. However, in the physical model the mixing effect is inherent in the model.

From these studies, we have concluded that realistic potential density distributions can be simulated in the model. Furthermore, suffcient additional knowledge has been gained to facilitate the establishment of a given field distribution in the model.

Studies of the Damming Effect of General Map Size

Several important observations were made concerning the damming effect of the maps. These are as follows:

1. The tests showed that flow laminae remain at their density elevations and will flow around obstacles rather than flowing over them.

2. The damming effect tends to truncate approaching density profiles, although some of the more dense fluid from below the map flows up onto the map.

3. The damming effect does not significantly deflect leading edge flow over the map neither vertically nor horizontally. However, horizontal deflection on the map away from the center of rotation

was noted 5 cm from the trailing edge of map for (H/H_T) less than 0.34 where (H_T) is troposphere elevation and for a map height of (H_g/H_T) equal to 0.23, where H_g is the ground elevation.

GENERALIZED OBSERVATIONS FROM PAST STUDIES

In the course of the previous investigations, several significant observations were made which support the present study. In addition, these observations may have a profound effect on the location of future ground seeder sites.

From the Leadville-Climax Map Study

1. Valley velocities scaled when free stream velocity was generated to conform to horizontal scale.

2. Density profiles were not successfully measured directly over the map. The most probable reason is that the light path from the density rod to the model wall was too long.

3. Mainstream transport of seeding, in or near valleys with channelized flow, followed the valley flow at the density levels at which they were generated. Thus, any benefit in high elevation target areas would be highly dependent upon generation elevation and turbulent diffusion.

4. Seeding in the bottom of valleys formed by ranges normal to the free stream flow stagnated. In regard to high elevation target areas, effectiveness would be entirely dependent upon turbulent diffusion.

5. The implication of Generalizations 3 and 4 are more significant when it is recalled that turbulent diffusivity approaches zero at flow boundaries.

6. Besides showing mainstream flow, the model clearly shows disturbances including initial lee wave action. However, amplification into turbulence is precluded by model design and the disturbances attenuate. To take advantage of lee wave spreading action, seeding must occur upstream of and near the elevation of obstructing range crests. Spreading occurred at successive ranges and in a direction towards the center of free stream curvature.

7. Any positive seeding effects demonstrated with the model will occur in the prototype. The effectiveness of the seeding will be augmented by turbulent diffusion.

From Prism Distortion Tests

1. These tests also indicated that seeded mainstream flow paths will tend to remain at the density level at which they were generated. Flow laminae will follow long tortuous paths around obstructions rather than flowing over them.

2. These tests also showed the effectiveness of lee waves with regard to the spreading action of the seeded material.

3. Tests with the prisms were not sufficient to determine whether flow action scaled from distorted maps adequately represented conditions in the prototype.

Implication of Tests in Regard to Further Modeling and Field Seeding

1. Capability of scaling velocity profiles in the model has been demonstrated.

2. Although the truncation of approaching density profiles might seem to be a disadvantage at first thought, this effect can add versatility in attaining scaling of density gradients. The advantage arises because the lower undesirable portion of the "S" shaped diffusion curve can be truncated with no large effect on the gradient above truncation.

3. The tests suggest a major difficulty in conducting wind tunnel studies for atmospheric studies. Confining the topography in a tunnel can force density flow levels to rise, whereas in the prototype they would seek paths around obstacles at their natural density levels. The opposite is true for our model. An isolated map in a flow field could provide density dropoffs and easier circumventing flow paths at the edges of the maps.

4. All distorted models should be verified or made to conform with sufficient approximation to the prototype action.

5. For the stratified liquid model, any positive seeding effect noted in the model will occur in augmented form on the prototype because of turbulent diffusivity that is superimposed on the mainstream flow.

6. Seeding should be from isolated peaks to get it into turbulence easier. The seeder elevation should be as close to target elevation density as possible.

7. To take advantage of lee wave action, the mainstream flow should be approximately normal to the crest of the range from which seeding is to be performed.

8. Seeding near or in valley with channelized atmospheric flow should be avoided.

9. The tendency of mainstream flow to remain at natural density levels and to travel around obstacles suggests difficulty in seeding from prairie slopes up into high mountain target areas.

FUTURE STUDIES

We propose that the stratified liquid model be used in FY73 to study the San Juan seeding area.

The objectives of this study would be to

1. Determine the mean plume axis of existing ground base seeders
2. Establish the location of additional ground base seeders to optimize the likelihood of covering given target areas.

The man-day estimates and costs to achieve these objectives are as follows:

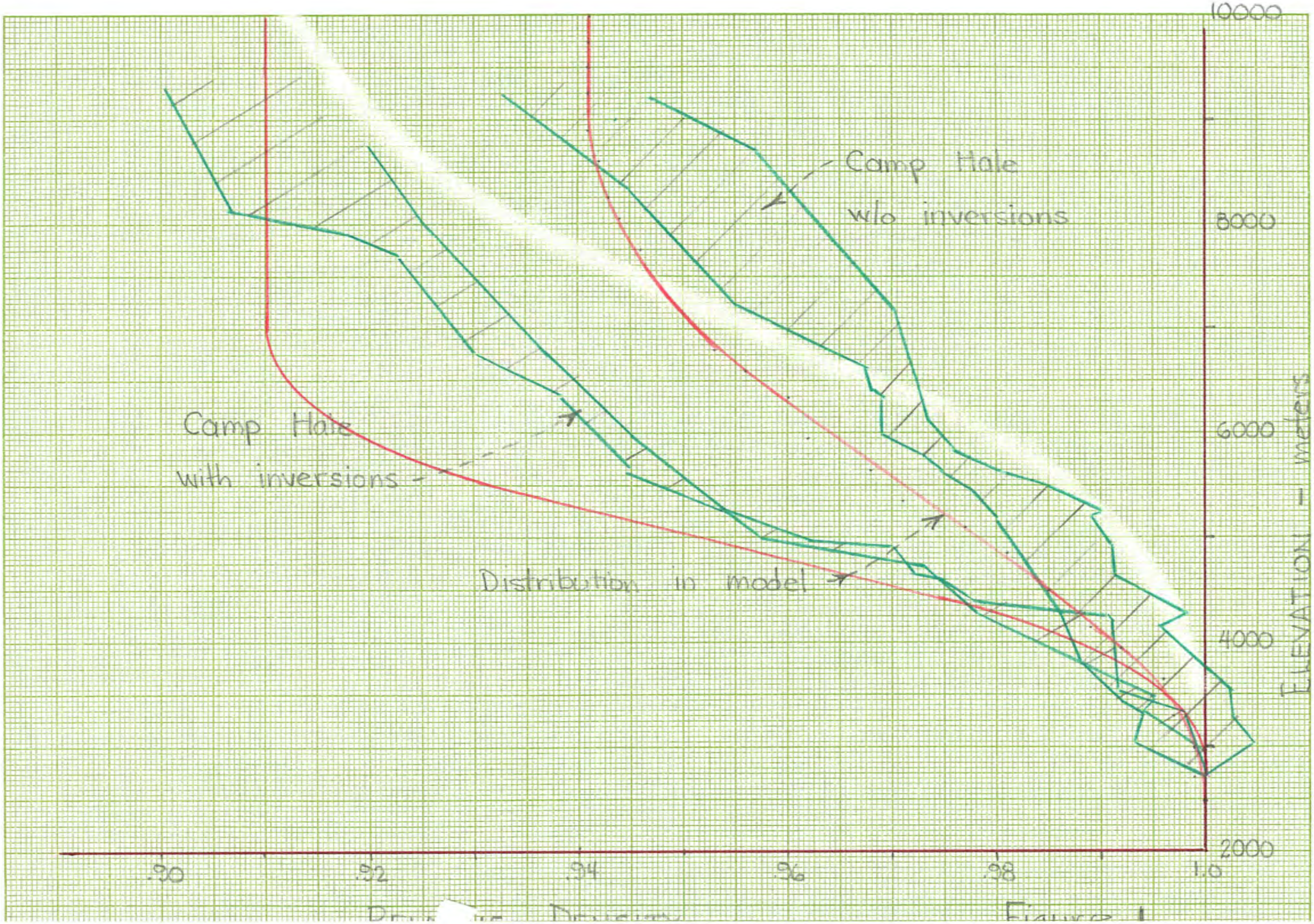
Task	Man-days
Prepare model to run	6
Test existing seeder locations with two density profiles and three separate wind directions	12
Test additional seeder locations with two density profiles and three separate wind directions	12
Report the results	15
Total	45

Costs

Code	DL+A	OH	Total	
1532	5,000	1,750	$6,750	[illegible]
1560	1,200	420	1,620	1500
Coded costs (ADP & Equipment)			430	500
			$8,800	

N.E. Wagner

Attachments


Camp Hale
w/o inversions
Camp Hale
with inversions
Distribution in model
10000
8000
6000
4000
2000
ELEVATION — meters
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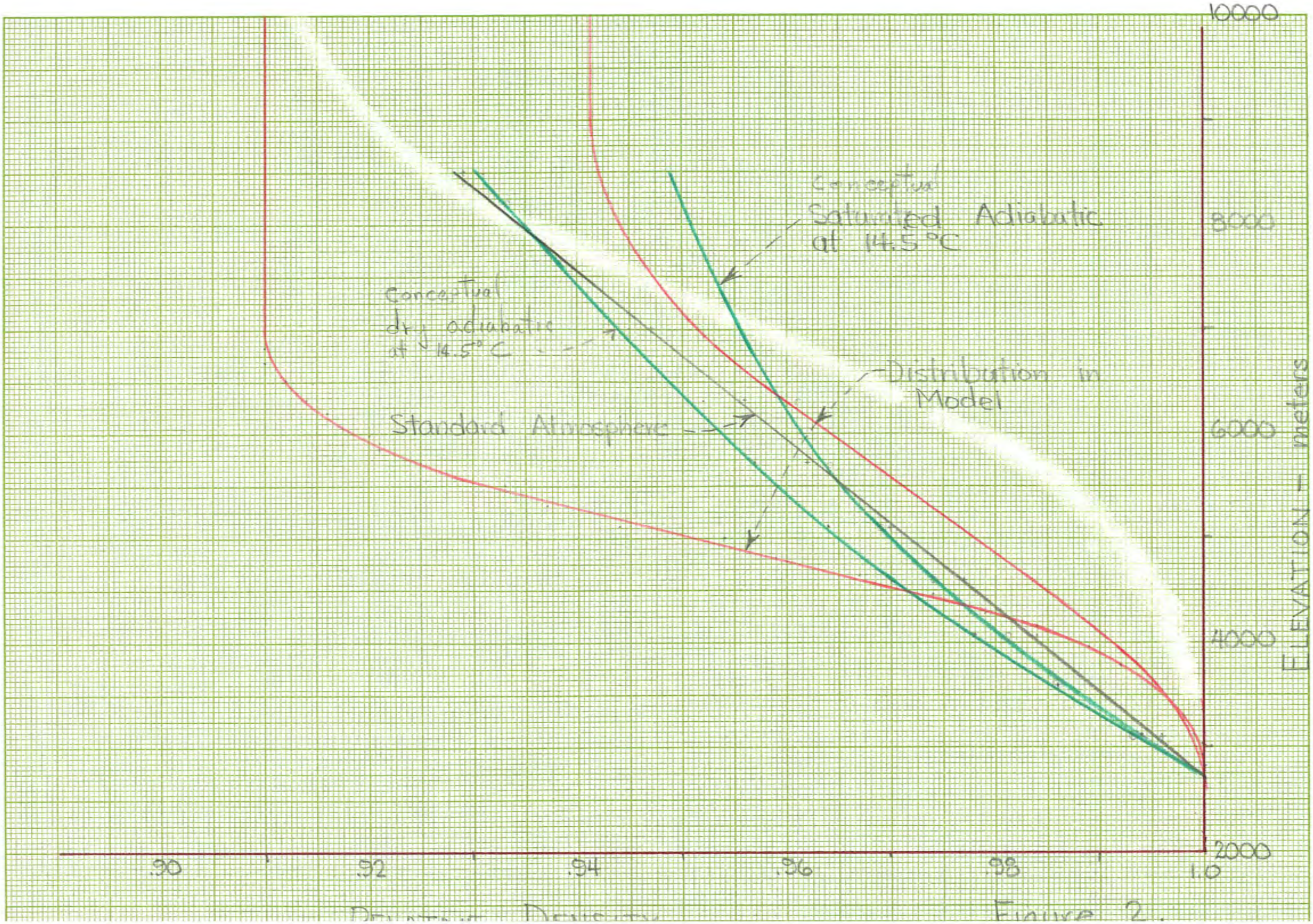
.92
.94
.96
.98
1.0


Conceptual
Saturated Adiabatic
at 14.5 °C
Conceptual
dry adiabatic
at 14.5 °C
Distribution in
Model
Standard Atmosphere
10000
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ELEVATION – meters
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1.0