OBSERVATIONS ON CONSISTENCY AND RELIABILITY OF FIELD DATA IN SNOW SURVEY MEASURMENTS

by

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INTRODUCTION

In August, 1850, a pioneer party was crossing what is now called Donner Summit in the central Sierra Nevada of California. A young married woman,Sarah Noteware, from Tioga County, New York, kept a journal of the event. She mentioned the arduous difficulties of hauling wagons up steep rock cliffs still mantled by deep snowdrifts, referred to tragedy and death experienced by a large group at the same mountain pass three years earlier (the Donner Party), and expressed surprise that so much snow was present that late in the summer. Precipitation records at San Francisco and Sacramento show that 1850 was a very wet year; hence late snow at Donner Summit. She then prophetically commented that their party had heard that it seldom rained in the Sacramento Valley at the western base of the mountains in the summertime, and that settlers there depended upon snowmelt from these mountains for water supply. Sarah and her husband later moved to the Carson Valley in Nevada at the eastern base of the Sierra Nevada. Their son, Warren, spent much of his adult life as a water engineer for ranches using surface runoff from the Truckee and Carson River Basins along the east side of the Sierra Nevada. He wrote and spoke of making periodic late winter and early spring visits to tall, isolated Jeffrey pine trees in the snow zone to measure the depth of the snowpack in order to estimate surface runoff during the melt season. There was no way to ascertain snow water equivalence but this was a rough precursor to snow surveying.

Sarah Noteware was my great-grandmother, Warren Noteware my grandfather. Thus, I may have been genetically doomed to become involved in snow surveying as a formal, scientific technique, which began in the first decade of the 20th Century in this same Donner Pass -- western Nevada region through the pioneering efforts of James Church at the University of Nevada. For 30 years I was actively engaged in measuring snow courses in the high elevation southern Sierra Nevada of California and in establishing snow survey programs in Afghanistan and Chile. My interest and involvement in field and academic aspects of snow hydrology continue down to the present and into the future. I estimate I have spent a minimum of 1,500 days in the field on snow measurement. This long experience does not qualify me as an omniscient expert, but does indicate considerable exposure to problems of data acquisition. Following are observations gleaned from this lengthy experience about conditions, problems, difficulties, and constraints in data acquisition which can be of value to users and interpreters of snow course and sensor data whatever method of acquisition is used, in North America and elsewhere. These observations deal largely with field measurements by the federal snow sampler, though much will apply to any instrumentation in data collection. With increasing development and use of sophisticated techniques for data acquisition and operational interpretation, trends I heartily endorse, it is salutary to remember that snow surveying depends upon accurate measurement of the water equivalent of snow on the ground at a given place at a given time. Much of this measurement is done now, will be made in the future, with the federal sampler.

CLIMATIC REGIME

First, as a professional geographer, I would point out that the commonly-named Mediterranean climate, winter-wet and summer-dry, is the most favorable type of climate in the world for successful stream-flow forecasting from snow accumulation. In mountain regions within this climate, of sufficient elevation for snowfall, 80-90% of the annual precipitation occurs by April 1 or May 1 in the northern hemisphere, 6 months later in the southern hemisphere. Thus, there is less chance of summer runoff forecasts being altered by the vagaries of significant late spring or summer precipitation. The Sierra Nevada Range of California has a classic winter-wet summer-dry Mediterranean climate regime, as do the mountains of North Africa, southern Spain, southern Italy,

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most of Greece, Lebanon, Israel, southern and eastern Turkey, Iraq, Iran, most of Afghanistan, and central Chile. The western portions of Oregon and Washington have modified Mediterranean climates. James Church was fortunate in having the favorable climate of the Sierra Nevada for his early work in snow surveying and streamflow forecasting. Only about 3-4% of the earth's land surface possesses this type of climate. Obviously, the methodology of snow surveying works effectively in other climates, as the Rocky Mountains, but with more uncertainties because of warm season precipitation.

VARIABILITY IN SNOW DEPTHS AND WATER EQUIVALENT

A commonplace, but necessary and vital, observation is that snow depth and water equivalent vary significantly in mountain snowpacks, often within short horizontal distances. This has great importance in locating sites for snow measurement. First, is the general difference in accumulation at different elevation zones. There is much speculation, written and oral, about the elevation of maximum precipitation zones in mountain ranges. All such speculation is plagued by paucity and often unreliability of data from the higher elevations. For the Sierra Nevada, conventional wisdom generally puts the maximum precipitation zone at about 1,600-2,000 meters in the northern part of the Range, 500 meters higher in the southern end. Snow course and snow sensor data from higher elevations, plus field experience, cast doubt upon these assertions. There is much evidence of little or no decrease, perhaps some increase, up to elevations of 2,800 meters in the north and 3,300 meters in the south, or even higher. Data acquired from snow surveying can be of great value in furthering knowledge of precipitation amounts at upper elevations where few other weather data are available. Such knowledge is vital in locating measuring sites for optimal coverage of a basin.

Apart from this general problem of the elevation of maximum precipitation is the variation from year to year in snow accumulation at different elevations. Warm storms may bring relatively great amounts of snowfall at high elevation, cold storms relatively large buildups of snow at low elevation. It is obviously highly desirable to have data collection sites from lowest to highest elevation of snow accumulation zones; in practice the uppermost elevations are often under-represented because of inaccessibility and difficulty of measurement. Some forecasting agencies are investigating, or actually using, forecast schemes which break a basin index into different elevation zones; a high snow index, a low snow index, or perhaps more categories. This procedure may be of considerable value in mitigating problems arising from elevational variations in snow accumulation from year to year.

Variation in Snow Depth

Much variation in snow depths results from topographical barriers, especially if oriented more or less perpendicular to prevailing storm-bearing winds. Some topographic snow shadows are massive, as the 3,000-meter east wall of the Sierra Nevada, where average annual precipitation may be 1,000 millimeters at the crest, only 150 millimeters at the east base of the Range, 12-15 kilometers distant, but 3000 meters lower. There is, moreover, much variation from storm to storm, and from year to year, of the snowline along this steep eastern slope. Within a mountain range there are numerous lesser topographic barriers which result in significant differences in snow deposition on windward or leeward slopes. Under snow-free conditions, it is usually not easy to determine these variations resulting from topographic barriers and prevailing wind patterns. There is <u>no substitute</u> for field winter-observations to locate areas of greater or lesser snow deposition. It is my long-term observation that significant snowdrifts that accumulate during the winter and those that remain to the end of the melt season occur overwhelmingly in the same locations year after year. Field experience can identify those locations. In heavy years the drifts are deep, in light years they are shallow; but they are in the same places.

Most of the snow courses in my experience consist of 10 sample points, at differing intervals, but usually about 15 or 30 meters apart. Nearly all courses show variation in depth and water equivalent from sample point to sample point, often significant. From year to year the ratio of these measurements from point to point remains very much the same; for example, sample point #6 on Bighorn Plateau nearly always has the highest values, while on the Bishop Pass course, point #9 is generally twice the amounts recorded on point #6. These differences are seldom evident visually on the surface; no obvious wind drifting or erosion has occurred. These ratios have been so regular in the Sierra Nevada, that I could often predict within a few percentage points what the average water equivalent on a specific snow course would be from measurement of the first one or two sample points -- a useful stratagem for winning wagers from inexperienced fellow surveyors. Such predictive potential never precluded the measurement of all sample points on the particular course, but does emphasize the regular variation in snow accumulation within short horizontal distances on surfaces not apparently subject to visible drifting or erosion. This regular variation does not always occur; alteration is most likely during light years when the influence of one or only a few storms of unusual intensity or wind direction may be significant.

It is vital for all involved in snow surveying to be aware of variation in snow depths with elevation, topography, and other more obscure reasons in order to locate measuring sites optimally, especially if one-point sites, or to change location of existing sites. This awareness can only be obtained realistically from field observation under winter conditions.

THE FEDERAL SNOW SAMPLER

The federal snow sampler, sometimes referred to as the Mount Rose sampler, in Chile as Monte Rosa, and only a little modified from Church's original instruments of 70 years ago, is still the basic tool used for snow data acquisition in much of North America and the rest of the world. In many areas where automatic sensors have been installed, there is often the need, presently and for many years to come, for continued hand measurement with the sampler to establish necessary correlations between long-term data and recently begun sensor data for use in forecast schemes. Moreover, the federal sampler is presently, and will be in the future, valuable for ground truth accuracy checks of sophisticated automatic sensors or remote sensing devices. So it behooves all persons measuring and using snow data to become thoroughly familiar with the sampler, particularly its problems and limitations. Reading and understanding of sampling manuals and attendance at formal training sessions are necessary, but there is no substitute (a familiar refrain) for ample field experience under the widest possible gamut of weather and snow conditions, preferably with a veteran surveyor who can impart wisdom gained from long association with the sampler. Using the sampler effectively does not call for great technical skill or extraordinary physical strength, but experience with all possible conditions, especially when adverse and unpleasant, is critical for consistency and reliability in data acquisition. The surveyor must be aware, and experience is the best teacher, that on a given day it may take 4-5 hours or more to measure a course which could be done in a half hour under optimum conditions, and that maybe a dozen or more samples are necessary at a single point to acquire a valid reading.

Special Problems

Following are problems I have found to be most common and troublesome in using the federal sampler. First, ice layers may form at the bottom of a snowpack during melt periods. Penetrating this layer with the cutter may be difficult to impossible, thus preventing undeniable proof of having reached the ground beneath the snow. Persistence may push through this ice, but an alternative might have to be careful comparison of depths and densities with nearby sample points without the bottom layer. A second problem with ice, or hard crustal layers, is their existence within a snowpack, especially deep snowpacks. In the Sierra Nevada, and elsewhere, such internal layers usually form during periods of clear weather with accompanying melt-freeze metamorphism. When later buried by subsequent large snowfalls, these layers persist at depth, often well into the melt season. They may well be identifiable throughout the winter; on an April 1 survey at a depth of 2 meters, the sampler will encounter a layer formed during clear weather in mid-January. Penetrating these layers and obtaining a sufficient core are frustratingly difficult. The cutter clogs, the sampler plunges beneath the layers, time and energy are consumed in large quantities, and profane vocabularies are exercised and enlarged. With particularly resistant layers, and in deep snowpacks with or without layers, it may be necessary to exert body weight in some fashion on the driving wrench. This is a delicate, painstaking operation with damage to the equipment all too likely. Obtaining accurate cores can be exasperatingly difficult and tedious; again experience and persistence are the best approach.

Another exasperating problem, all too common, is for snow to stick inside even the best-coated tubes. This is most frequently in mid-day when air temperatures are distinctly warmer than those within the snowpack. Cooling the sampler before use on the snow surface or in shade, or sampling in early morning or late afternoon, may avoid or alleviate sticking problems, but not always. Travel schedules often dictate that the course has to be measured near mid-day. Frequently, the sticking is confined to one tube, and once started, will persist. Carrying an extra tube, and substituting it for the troublemaker, is a possible solution. The use of strong expletives may help. Carrying a seemingly extra tube or two, or having them stored safely close-by, is also extra insurance against confronting unexpectedly great snow depths at sample points. It is extremely awkward and embarrassing for a field survey team not to have sufficient tubing to reach the ground. This tragedy can particularly occur on extended survey trips of many days when major snowfalls may occur en route.

Ponding on snow courses during active snowmelt causes problems to which I find there may not be adequate answers. Courses with prevalent ponding are prime candidates for relocation or abandonment. It can be painfully obvious to the field surveyor, when watching free water run out of the sampler, that this water has originated elsewhere, and gives a distorted value. Possible responses -- letting the free water run out before weighing, taking samples nearby without ponding (maybe hard to find), estimating water equivalent from water-free samples, discarding questionable points from the course average -- all have limitations when significant ponding affects much or most of the course. Ponding is truly one of the most serious constraints on accurate data from the federal sampler.

ACCURACY OF THE FEDERAL SNOW SAMPLER

Various tests by different agencies have concluded that the federal sampler overmeasures water equivalent, up to 10-12% in deep snowpacks. Many times from my field experience I am convinced the reverse is true -- that the sampler does not catch all the snow in a sample, primarily because of clogging or plugging of the cutter (by layers) and the difficulty of picking up light powder snow (the sampler pushes light density snow aside). I would like more research into this matter, especially under conditions encountered at field sites. Correlations between adjacent hand-sampled and snow pillow sites often show very similar water equivalent values. Do both the federal sampler and the pillow overweigh at the same ratio, or are they both relatively accurate measurements of true water equivalent?

It is often argued that measurement of true water equivalent is not critical, or even desirable, in an index method of streamflow forecasting. But an increasing use of snow data for purposes other than volumetric forecasts calls attention to the value of true water equivalent readings. Examples of such other uses are in ecological or biological studies to ascertain actual water available to plants and animals, and data to estimate roof snow loads. It should be remembered that at high elevation in mountain ranges like the Sierra Nevada, the Cascades, and the Rocky Mountains, the only available precipitation data may be from snow courses and sensors.

LOCATION OF SNOW COURSES AND SENSORS

Most snow courses in western North America were established decades ago, many in California in the 1930's, a few earlier. This was before criteria for evaluating a good or bad location for a course were well understood (still a problem today). Probably every surveyor and user of snow data longs for a Utopia where one could start from present knowledge of snow distribution and locate anew a rational system of measuring sites. But there is the eternal dilemma -- when enough years have elapsed to assess the value of a particular snow course in streamflow forecasting, it is difficult to change location because of the additional years necessary to evaluate any other site. Essentially, forecasters are locked into an existing network of sites because of the long record necessary for proper correlation of snow index with historic runoff.

Despite this dilemma, I argue there is need for continual evaluation of the utility of each course or sensor, and changes can and should be made. Understandably, in the development of snow surveying, emphasis was on abundance, not scarcity, of snow courses. However, with accumulated experience and longer data series, close scrutiny may well show some courses are of little value in forecast schemes and could well be abandoned. This is not to be done lightly. Redundancy is ever attractive. There is always the chance that road, commercial, or recreational development, or changes in public land policies in parks and forests make long-term sites no longer tenable, requiring the use of backup, perhaps less valuable courses. Presumably, sensor sites have been chosen with much careful study in recent years and would be costly to move or abandon. Even here, I urge continual assessment of the value of each site, and willingness to change or discontinue.

A simple and awkward, but solvable, problem can be not having course markers, storage gauges, sensor antenna, and other instrumentation high enough off the ground to avoid burial in the truly big snow years. Recurrence interval studies have often been inadequate indicators of maximum accumulation. The winters of 1969 and 1983 made many believers in California. I advise careful investigation to estimate greatest possible snow depths at a specific site, then place all critical installations at least 3 meters higher than this estimate. I have spent hours and hours in digging out installations, and sometimes have not found marker signs or poles because of burial in big years.

Changes within a given course are always possible. Relocation of troublesome sample points or reduction of the number of points may be done without altering significantly the correlation value of the course. In considering change of location, abandonment of particular sites or changes within a course, input from field surveyors can be invaluable. They will often know from experience which courses have problems with ice layers, with ponding, with undue drifting or erosion, with avalanches, with travel access. A particular contribution from field surveyors can be to identify difficulties with recently established sensor sites, and perhaps bring about location or other changes before the record from the deficient site becomes long enough to make alteration difficult, and the forecaster is stuck with another undesirable site. Still another contribution from the field surveyor is to describe changes in the years in vegetative growth such as trees, at snow sites which might modify snow deposition patterns. One obvious response to this problem is careful and continual summer maintenance of course and sensor sites.

DESCRIPTION OF COURSE AND SENSOR SITES

It would be useful to have more complete and detailed descriptions of snow measuring sites than are generally available, or at least that I have seen and used. Such elements; as type, height, and density of vegetation, height and degree of slope, general rock and soil types, travel access routes; could be included. More complete descriptions of site locations could make it easier for those unfamiliar with the site to find it, especially under adverse weather conditions. Moreover, these descriptions could be valuable for all users of snow data, including those not directly involved in volumetric forecasting. It can be distracting and time-consuming for forecasters to answer needs and demands of other persons interested in snow data, but after all most forecasting offices are public agencies, and a certain amount of public service is appropriate.

A Special Problem of Course Location

A specific problem arising from course location has often concerned me from experience in the field. Especially in dry years and at lower elevations but maybe in wet years as well, the following situation may occur. A snow course on a north-facing slope, or on a flat bench with late snowmelt, will show no change in average water equivalent in a dry month, say from February 1 to March 1, but it is obvious from visual observation in the field that south-facing slopes in the vicinity have lost significant snow cover during the month. There is less snow and water equivalent in the area of the course, but the course measurement shows the same index value, or maybe even a slight increase. The same problem applies particularly to all courses of low average water equivalent. Was there recent snowfall up to the date of measurement with substantial snow cover on all slopes surrounding the course, or was it dry for weeks preceding the measurement with significant reduction of snow cover and water equivalent on sun-facing slopes? Can the forecast schemes make allowance for these discrepancies? A theoretical answer to this problem is to analyze runoff data see if the melted snow water has passed the stream gauge, but runoff data is often incomplete or not in time for the forecast. And some of that depleted snow on the sun slopes may have sublimated directly into the atmosphere and be lost to the runoff.

TRAVEL

Sooner or later, everyone involved in snow surveying and stream-flow forecasting may have to or want to travel to and from measuring sites. Field surveyors do this regularly; California still has a 10-12 day trip on skis, longer with storm delays, 4 times a winter in the high elevation Kern Basin of the southern Sierra Nevada. This may seem romantic and archaic, but has proven to be feasible and cost-effective for years. Others will travel for desirable field experience (I recommend all in the profession to do so), for maintenance purposes, from breakdown in mechanical travel devices, or for personal challenge or pleasure. All the usual homilies about physical fitness, skill and practice in using equipment, as skis or oversnow vehicles, maintenance of personal and mechanical equipment, and preparation for possible overnight bivouacs, are mandatory. Extended training sessions, as the Soil Conservation Service Westside Conference, are valuable and should be attended by all who might have to or want to travel over snow.

I offer these additional comments about travel. Avalanches constitute the most serious and ultimate danger. Special training in knowledge and recognition of avalanche conditions is vital to safe travel. Often there will be no formal avalanche prediction in little-frequented back country where snow sites are located and conditions can change while a trip is in progress. The field traveller needs to be his own forecaster. Specific mountain areas often display characteristic, repeating avalanche patterns, which can become familiar to the experienced and perceptive surveyor. For example, in the Sierra Nevada most destructive avalanches occur when heavy, wet snow, perhaps mixed with rain, falls upon a crust formed from days of melt-freeze metamorphism, especially if the snow depth beneath the crust is sufficient to cover most logs and boulders. Depth hoar, important in avalanche incidence in colder interior mountains, can be a factor in the Sierra Nevada, but overloading from heavy new snow on pre-existing crusts is by far the most common danger. Some winters, as 1987, a low snow year, bring very few avalanches in the Sierra. On the other hand, in 10 days in mid-February, 1986, just the previous year, as much as 2,000-2,500 millimeters of water equivalent fell in the mid-elevations of the Range, resulting in an historically unprecedented series of massive avalanches. It would have been most imprudent for anyone to have been travelling anywhere in the snow zone during these conditions.

A less-publicized difficulty in travel in winter is the poor or zero visibility associated with fog or wind-blown snow in intense storms, which can occur suddenly and it can persist for hours. A particular hazard is to travel into the face of a gale or hurricane force wind with blowing snow. The most veteran traveller will tend to veer away from the strength of the wind, and very soon be off course. Knowing the terrain in all seasons is most helpful; even fleeting glimpses of familiar landmarks can orient a bewildered traveller in poor visibility. A valuable instrument for meeting poor visibility is a reliable compass, a necessary item in every travel kit. A compass may be vital in following the proper direction of a line of sample points on a snow course, presumably indicated on a course map, if the course markers cannot be seen, which can certainly happen. In good visibility, a compass in conjunction with an adequate map can be most useful in travel in unfamiliar country.

Weather and Travel

In every country where I have been, the local language has the equivalent of the maxim, "Only strangers and damn fools predict the weather in these parts." This is usually said with an air of complete certitude. I submit it is nonsense! Specific mountain areas have characteristic weather patterns, which can be predicted with better than random success by a perceptive traveller who is neither a stranger or a damn fool. This is particularly true for short-term events lasting a half day or less, but which may definitely affect the safety and welfare of the traveller. It helps to have a solid foundation in meteorology, but careful observation of wind direction and speed plus cloud sequences in a particular region can enable the snow surveyor to make useful and operational local forecasts, not infallible (no one does that), but very conducive to successful travel. As with avalanches, professional analyses will frequently not be available; the snow traveller must be his own forecaster. The longer the experience with varying weather events in a given region, the more error in local forecasts can be reduced.

RELATIONSHIPS BETWEEN FIELD AND OFFICE PERSONNEL

In every human organization with functions that can be divided into field or office operations there seems to develop an awareness of the differences by those who do primarily field or office work. To some extent this awareness and self-identification with field or office may be healthy and promote greater effort in a spirit of reasonable friendliness and rivalry. But in all too many instances one group does not know or appreciate what the other is doing or thinking, and unproductive ignorance, apathy, or even hostility characterize relations between the two basic groups. This certainly can, and all too often does, happen in snow surveying agencies. Office types may regard field personnel as size 44 coat, size 4 hat types who have trouble in using words of more than two syllables, while field types may spend hours on data-gathering trips or in snow-bound cabins discussing the manifold shortcomings and impracticalities of the office types. Being one of the few persons with extensive experience in both field and office operations, I have had much opportunity to observe misunderstandings and conflicts between the two factions and have long tried, with varying success, to bridge the gap between them.

I have no ready or sure-fire remedies. Probably the best solution is to combine, as far as possible, field and office functions within the same person, who then acquires some understanding of all facets of the operation and tends not to identify strongly with any one group, or faction. Given demands of costs, time, training, job prerequisites, personal inclination, and other considerations, this combination of field and office functions in one person is often impractical, or downright impossible.

The next best approach is to make everyone in the organization as familiar as possible with all phases of its operations, and wherever and whenever possible experience firsthand what those phases consist of and what they demand of the participant. These efforts will never reach perfection, but will result in less friction, greater harmony, and more efficient work, if systematically and diligently pursued. Many analysts have attributed a significant reason for Japan's apparent success in trade and industry in enlisting the willing participation of all workers in the end product and success of the organization. Snow surveying groups can do the same, and the truly successful ones do just that. To me, a healthy sign is when individuals in any organization use the pronoun "we" in discussing work, rather than "they". "They" too easily become the faceless idiots in some other part of the group, as field or office types.

Field personnel in snow surveying are often local residents in or near snow country, or free-lance workers who like to ski or travel in alpine country. They may have little knowledge or interest in the reasons for data gathering or how the data is processed or used. Motivation for measuring courses accurately in adverse travel and weather conditions may be limited. Consistent and reliable data suffer. If sincere and diligent efforts are made to enlist the interest and participation of the field personnel in the purpose and product of the whole program, the "they" becomes "we", consistent and reliable data prosper.

Office personnel too frequently are not aware of the constraints and limitations in gathering data in the field and of the practical and pressing problems that field workers encounter. It is essential for office personnel to experience at least some of these constraints and problems firsthand in the field. The "they" also can become "we". There is another benefit, besides greater group harmony, resulting from office experience in the field. Forecasters and data massagers can become more efficient and astute interpreters of basic data. They will develop a more realistic picture of the snow resource with which they are working, and will identify errors and inconsistencies in the data more readily and accurately. To belabor the point, there is no substitute for field experience at any level of participation in snow surveying. I recommend that each office working in snow surveying delegate one staff member to be particularly concerned with checking consistency, accuracy, and completeness of basic field data, certainly someone with extensive experience and knowledge of field conditions in the office's area of responsibility. In larger offices these duties could well be written into job descriptions.

SNOW SURVEYING IN FOREIGN LANDS

Snow surveying as a formal scientific discipline began in western United States, and has been exported to many other countries thereafter. It was my good fortune and rewarding experience to have been engaged in setting up snow survey programs, especially field measurement sites, in Afghanistan and Chile in the latter 1970's. Afghanistan is one of the least developed countries in the world, in terms of technology, industry, and per capital income. Chile is much more developed, is on the verge of joining, for better or worse, that group of generally recognized highly developed nations like the United States or Canada. Problems of instituting snow survey programs in the two countries were similar in many respects, despite differences in economic development. Both countries have Mediterranean winter-wet, summer-dry climates, favorable to snow survey methods developed in the United States. Some major problems I encountered abroad may be of interest to snow survey participants in the United States and Canada. Establishing a program from scratch emphasizes and accentuates basic problems in snow surveying that may become obscured with long exposure to the discipline here in western North America. It does lead to a back-to-fundamentals approach. And it reinforces the venerable maxim that to teach a subject well, the teacher must know his subject well.

Special Problems in Foreign Lands

Access to the snow zone of high, rugged mountains in other countries may be far more difficult than in the United States or Canada. There was not one winter-maintained road in Afghanistan where I worked, very few in Chile. Aircraft with experienced pilots are likely less available and more expensive. Helicopters might well be the sole jurisdiction of the military with delicate political overtones of use. Moreover, I am not that sanguine about flying around 6,000 meter peaks without knowing something about the experience of the crews and the maintenance of the aircraft. Chile presented avalanche problems far greater than what I had seen in the United States; such problems were also severe in Afghanistan. Some apparent ground travel routes to favorable measuring sites were prohibitively dangerous because of avalanche susceptibility. Very few peopled skied or snowshoed in Afghanistan, and the only common oversnow vehicle for depths of one meter or less was the camel. Skiing was more common in Chile, but cross-country travel in winter was not usual practice, much like what James Church encountered in the Sierra Nevada at the turn of the 20th Century.

Difficulties and dangers of travel overseas argue for the establishment of automatic sensors and remote sensing, if possible. However, taking a sophisticated, high technology approach requires sufficient resources and trained personnel to operate and maintain the program. In Afghanistan meeting these requirements was unlikely in the 1970's; in Chile less doubtful, but not certain. My emphasis was upon establishing the most reliable method of data acquisition in the beginning, then add more sophisticated automated elements later. This meant using the federal snow sampler, graduated in metric units, on snow courses measured by local residents in mountain areas who could be relatively easily and quickly trained to carry on the program after the foreign "experts" left. Another recommendation was to use aerial photo surveys of snowcover in inaccessible basins. In Afghanistan, a beginning of a workable snow survey program has been indefinitely delayed because of revolution and continuous guerilla warfare in the snow zones of that country. Chile has an ongoing snow survey program, much of which was established several decades ago in portions of the Andes other than where I was working. James Church, himself, went to Chile in the 1950's to inaugurate snow surveying. It must be realized that political upheavals in other countries are an ever present threat to the operation of the best-designed snow survey programs.

Developing countries are likely to want results immediately from spending money to inaugurate water management programs like stream-flow forecasting from snow measurements. I had much trouble convincing Afghans that it would take ten years or more, 5 years as an absolute minimum if there were extremes of precipitation during those 5 years, before a correlation between a snow water equivalent and precipitation index and streamflow in a given basin could be useful in streamflow prediction. There would be sardonic questions from Afghan officials, "Is this the best the most advanced and powerful nation in the world has to offer?" Americans and Canadians may get the same queries at home. I hasten to add that I was treated in friendly and cooperative fashion in both countries, and further add that my field experience in the United States was greatly appreciated and helped foster rapport with field personnel in both areas.

I went to Afghanistan first in summer and fall, to locate snow measurement sites, then returned the next two winters to instruct Afghans in travel and measurement and to assess the desirability of course locations. In Chile I went first in the winter, located measurement sites and reconnoitered travel access with snow cover, returning the next summer for critical appraisal. Either sequence can be effective, but as discussed earlier in this paper, I strongly recommend locating measuring sites under winter conditions with snow cover, if at all possible. There is very likely little reliable weather data available in high mountain regions overseas, even less than at home, so personal observation of snow conditions becomes more imperative in proper location of snow courses or sensors.

Tact and diplomacy are worthwhile traits in any human communication, but are especially valuable in dealing with technicians, professionals, and officials of a developing country on a project like establishing a snow survey program. These people are very sensitive to being perceived as backward or incapable; the "foreign expert" must be fully aware of these sensitivities and avoid any impression of representing a superior society. He is there to impart knowledge and skills of a useful technique with which he is familiar; not to belittle a society which hopes to benefit from his expertise.

CONCLUSIONS

In this paper I have presented observations, evaluations, and recommendations on consistency and reliability of field data in snow survey measurements. These comments are drawn from over 30 years experience in snow surveying in the Sierra Nevada of California and overseas in Afghanistan and Chile. Pervasive themes throughout this paper are that snow surveying depends upon the accurate and complete gathering of basic data in the field and that all personnel involved in snow surveying at whatever level can acquire much knowledge of and valuable insights into the problems and constraints of data acquisition from direct experience with field measurements and winter travel to data sites.