ADAPTING MELTWATER SUPPLY TO MEET IRRIGATION DEMAND IN HIGH MOUNTAIN AGRICULTURAL COMMUNITIES: THE EXAMPLE OF HOPAR VILLAGES, PAKISTAN

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ABSTRACT

Design, construction and maintenance of irrigation channels are intricate tasks throughout the Upper Indus Basin's Karakoram Mountain Range. The people of Hopar Valley have, over 900 years, transformed a rugged and arid high mountain valley into an agricultural oasis of 280 hectares of cultivated terraces and 130 hectares of irrigated alfalfa pasture. In so doing they have overcome the environmental challenges of rough and unstable terrain, low precipitation, short growing season and relatively distant, low quality water supply. Much of this accomplishment is due to the painstaking development of an irrigation network of over 200 kilometres of channels which link meltwater from snowfall above 3600 metres to terraces between 2500 and 3000 metres, where temperatures are warm enough for single crop cultivation. The source of Hopar's water supply, meltwater from snow and ice accumulations up-slope from cultivation, is reflected in both the physical and social aspects of irrigation water distribution and allocation.

1. WATER SUPPLY

1.1 Introduction- The people of Hopar Valley have, over 900 years, transformed a rugged and arid high mountain valley into an agricultural oasis of 280 hectares of cultivated terraces and 130 hectares of irrigated alfalfa pasture (Figure 1). In so doing they have overcome the environmental challenges of rough and unstable terrain, low precipitation, short growing season and relatively distant, low quality water supply. Much of this accomplishment is due to the painstaking development of an irrigation network of over 200 kilometres of channels which link meltwater from snowfall above 3500 m to terraces between 2500 and 3000 metres, where temperatures are warm enough for single crop cultivation.

Figure 1

Surveyed by Butz, 1986

The areal extent of intensive cultivation is generally limited to an upper threshold of about 3000 metres by altitudinal temperature gradients (see Whiteman, 1985). However, some potatoes, green-fed grain and fodder crops are grown at summer pastures as high as 3400 m. Meanwhile, at and below these elevations agriculture is inhibited by low precipitation and high evaporation which combine to produce a negative moisture balance for the period of peak water need. Only by utilizing meltwater from snow and ice accumulating in the more humid environment above 3600 metres is agriculture possible. Most of this accumulation is released between mid May and early August. Thus, Hoparis are able to exploit climatic conditions from two elevation zones, one with favorable temperatures and the other moisture supply, to create a single favorable crop-growth environment.

Several conditions of Hopar's unmodified meltwater supply prevent it from being optimum for irrigation: a) poor accessibility of water to fields, both vertically and horizontally; b) uncertainties of timing, in volume and in consistency of discharge; c) water quality problems in the form of high sediment and low temperature, and d) vulnerability to failure in slope materials above channels, and channel walls themselves.

However, irrigators are able to confront and modify, if not remove, these problems at three levels within the channel network: 1) primary channels flowing from the meltwater stream to the cultivated area; 2) village level channels distributing water within the lands of individual villages; and 3) field level ditches which channel water between and within individual plots.

The effect of manipulating the flow of meltwater at a series of levels is to create an irrigation supply which is increasingly clean and warm, less variable, more manageable, and more predictable as it flows toward the fields. This chapter describes Hopar's meltwater supply, and examines the way in which farmers ameliorate its negative characteristics and their attendant risks at various levels of the channel network.

1.2 Hopar Nala Basin- Most of Hopar's irrigation water is supplied by melt from permanent snow and ice patches, and seasonal snow cover accumulated in a series of cirques between 3600 and 4900 metres. Intermittant streams drain from these into a steep east-facing gully-cum-gorge cut by a meltwater stream, locally called a nala. The catchment area is approximately 11.5 square kilometres. About 2.1 square kilometres of this is covered by ice. Another 6 square kilometres is covered by permanent snow. Seasonal snow covers the entire basin in winter, but retreats from a lower elevation of about 3600 m in early April to 4100 m by mid July. Local persons indicate a maximum transient snowline retreat to 4500 m. Above that altitude and in shaded or north-facing side-valleys accumulation appears to equal or exceed melting. Avalanche redistribution downslope from the higher, steeper areas contributes to dense, dirty snow deposits as far down as the mouth of the basin.

1.3 Snowfall Outside Hopar Nala Basin- Winter snowfall on the Western slopes above cultivation and outside of the main source basin supplies small quantities of meltwater to Hopar. These steep slopes receive direct radiation from sunrise to mid-afternoon, so that by the middle of May almost all snow has melted, except in a small area to the north of Hopar's main meltwater basin. This micro-basin, between 3800 and 4100 metres is sufficiently high and shaded to retain the majority of its snow until early July, after which it releases peak afternoon discharges of approximately 0.2 cubic metres per second (cusecs) until late August. Hoparis have diverted the small meltwater stream into their irrigation system.

The cultivated area of Hopar receives snow accumulations of 60 to 90 centimetres in the winter months, which, according to villagers, is usually gone by early March. In 1986, early snowfall occurred, but quickly melted in early May. Germination and early growth in some fields relied solely upon moisture from that melt. The same was observed in May 1987 (Ken Hewitt, personal communication).

1.4 Hopar Nala Water Flow- Hopar Nala flows continually. However, between November and March discharge is less than 0.1 cusecs. It begins to increase near the end of March, when shallow snow patches and avalanche deposits near the mouth of the basin start to melt. Flows increase as greater radiation, and the upward migration of warmer temperatures, allow melting at altitudes with progressively deeper and more extensive snow accumulation. However, during March, April and early May melting is very uncertain and highly irregular.

By late July melting occurs throughout the source basin. This includes avalanche deposits at 3600 metres and perennial snow and ice patches above 4900 metres. As a result, peak afternoon discharge then reaches 11 cusecs. Melting of this magnitude occurs into early August, causing rapid depletion of the remaining seasonal snow pack. Thus, in late August a decline in melting corresponds with diminishing snow surface and decreasing heat input until base winter flow resumes in November.

The period of substantial melt is prolonged by the existence, over a variety of aspects and elevations, of several types of snow ranging from seasonal snow through perennial snow and avalanche deposits to ice. It should also be noted that discharge variability throughout the season and between seasons, is relatively great because discharge through Hopar Nala is largely (not wholly) from seasonal snow, rather than perennial snow and ice (Young, 1977; Whiteman, 1985).

Several observations may be made concerning Hopar Nala's diurnal flow. The predominant aspect of the basin is easterly, so peak daily discharge occurs relatively early in the day; around 1400 hours in mid July. (This contrasts with observations at Askole, a village in Baltistan with similar altitudinal characteristics but a south-facing aspect. There peak flow occurs around 1730 hours). Early onset of melting is also enhanced by particularly steep east-facing valley walls which allow almost perpendicular exposure to direct radiation early in the morning.

The presence of a variety of slopes, aspects and snow types has the same effect upon diurnal melt as it has upon seasonal discharge; it tends to prolong melting, and diminish peaks. Exposed ice and avalanche snow respond to energy input more quickly than seasonal snow, because they tend to have lower albedo. However, they may receive lower inputs of radiation because of their small area compared to mass, and their position down in the gorge where shade and cold air drainage inhibit warming. Relatively fresh snow reflects most incoming radiation, and is able to absorb considerable water before releasing it downslope (Young, 1977). These factors combine to produce a broad, relatively flat discharge curve.

As the melt season progresses snow both compacts and collects dust and debris. The consequent reduced albedo and higher absorption capacity results in a diurnal melt which shifts toward morning as the summer progresses. Increased exposure of dense and dirty avalanche deposits, perennial snow, and ice as seasonal snow melts enhances this trend (Young 1977). Discharge measurements taken in 1986 indicate that peak discharge migrated approximately two hours toward morning from mid May to late July. This migration follows the path of sun height penetrating the gorge as summer progresses.

1.5 Water Characteristics- Meltwater entering irrigation systems is characterized by low temperatures and high sediment. During the period of investigation temperatures at Hopar ranged from 0.5 degrees celcius where the highest channels cut off from the nala, to 7.0 degrees at the lowest cutoffs. Channels cut off to seven degrees at the lowest, during the 1986 field season. Sediment studies were not conducted. However, it is apparent that steep and unstable slopes, and heavy avalanche activity contribute to high bed and suspended loads in Hopar Nala.

2. WATER SUPPLY AND IRRIGATION DEMAND

2.1 Introduction- Meltwater flow through Hopar Nala is most useful to the community if supply meets demand with minimal input of capital and labour. This relationship is summarized under four categories: volume, timing, accessibility, and water quality.

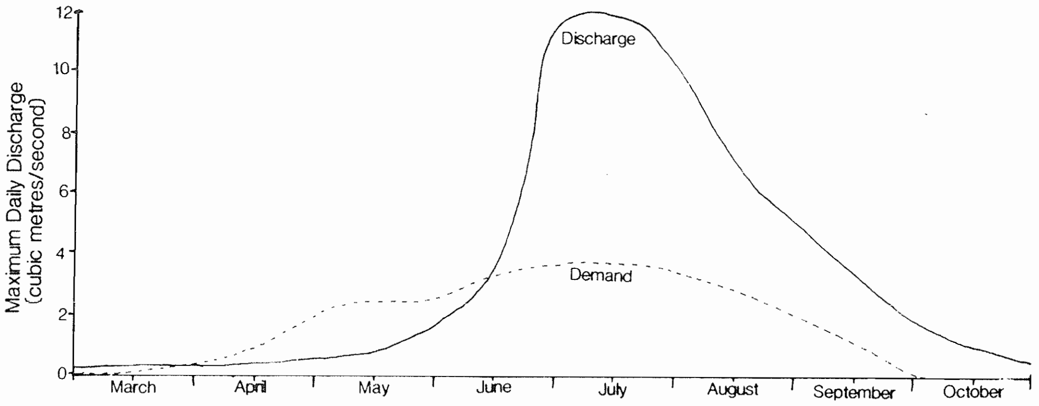
2.2 Volume- Hopari irrigators require sufficient volume throughout the irrigation season, and predictable flows from year to year. The main nala carries abundant flow for the period of regular, intensive irrigation from June 15th to August 1st, and for the progressively lighter irrigation that occurs until potato harvest in September. Flow is insufficient from mid May to mid June. However, early melt from snow coverage outside the nala-basin helps to ameliorate water shortage in terraced areas, and triggers alfalfa growth on slopes above 3000 metres.

Volume of melt-season flow is more predictable in Hopar than in rainfed basins. Several studies indicate that glacier meltwater tends to regulate streamflow by compensating for vagaries in temperature and precipitation (Young, 1977; Meier, 1973). This statement holds true for Hopar, although it is primarily snow covered, because when seasonal snowfall fails perennial snow and ice melts more readily. It is likely that the result is a relatively consistent flow from year to year, which does not depend greatly upon variable Karakoram precipitation conditions. Unfortunately for irrigated agriculture, this consistency applies more to total volume of seasonal melt than to its timing.

2.3 Timing- The average seasonal timing of meltwater supply to Hopar is excellent relative to precipitation timing in the agricultural zones of the Upper Indus River Basin. In contrast to precipitation, which occurs primarily during the cold season, melting above Hopar coincides remarkably with maximum temperature, and crop water requirements (Figure 2).

Figure 2

HOPAR NALA DISCHARGE & IRRIGATION WATER DEMAND
Estimated Maximum Daily Values



SOURCE: Field Investigation, Butz 1986

Average diurnal discharge is also close to ideal for irrigation. A relatively low, east-facing snow accumulation zone means that farmers can begin irrigation early in the day while evaporation is low, and finish before sundown. Since the release of meltwater peaks and declines gradually, flows rarely reach hazardously high levels, and irrigation can occur throughout the day.

While the timing of discharge suits irrigation demand on average, inconsistency in timing due to winter snowfall characteristics and summer melting conditions is problematic. If most winter snowfall occurs early, it will settle and accumulate a thin dusting of debris. The consequent decrease in albedo may cause peak melting before peak irrigation need. If, on the other hand, major snowfalls occur toward spring, melting will be inhibited by relatively great albedo (Meier, 1973; Young, 1977). In basins where fresh snow covers perennial snow and ice, low seasonal coverage causes earlier and higher summer melt. In addition, cold and cloudy spring conditions delay and inhibit melt. If certain conditions combine villages may receive most of their irrigation before or after peak irrigation demand. For example, in 1986 Hopar's spring weather conditions were unusually cold and wet, and combined with heavy and late winter snowfall. This produced seasonal flow which was, according to locals, exceptionally low until mid June, and slightly below average throughout the irrigation period.

2.4 Accessibility- The main part of the Hopar meltwater basin begins approximately 600 metres above and one kilometre distant from the upper limits of cultivation. It is therefore much more accessible than many Karakoram villages, especially since the nala dissects the lower end of cultivation. At the same time building, maintaining and repairing channels from the stream to cultivation across steep, rocky and extremely unstable terrain poses important financial, labour, and organizational difficulties to the community.

2.5 Water Quality- Crop cultivation is subject to two water quality problems; low temperature and high sediment load. Water temperatures never exceed two degrees celcius at the highest channel cutoffs, and remain between four and seven degrees at lower cutoffs. Unless these temperatures increase before water reaches crops, soil temperature and growing season are significantly decreased.

Meltwater irrigation systems are commonly subject to high sediment loads (Whiteman, 1985). Hopar is no exception due to steep slopes, unstable terrain, and abundant avalanche activity. If sediment is not trapped above the cultivated area, it has the potential to clog channels, damage water mills, choke seedlings, and raise terraces. At the same time some sediment input is required to maintain non-organic soil constituents.

2.6 Summary- The community of Hopar depends on a water supply which seems in some aspects ideal for irrigation, and in others very problematic. The following sections examine how the irrigation system ameliorates water supply problems through levels of increasing meltwater manipulation and adaption.

3. PRIMARY CHANNELS

3.1 Introduction- Hoparis begin controlling and distributing flow at the level of primary channels. This involves overcoming important physical problems, and maintaining certain social imperatives. Physical problems include: a) directing water from the mainstream into channels; b) finding and constructing a route from cutoffs to terraces; and c) maintaining channels against geophysical hazards.

These are discussed below. Section 3.4 examines the following social necessities of primary channel water distribution: a) efficient labour organization; and b) equitable allocation of water among villages.

3.2 Physical Problems- Twelve primary channels diverge from the nala between 3150 and 2550 metres, and direct water to a network of smaller channels within village areas. Potential flows range from .004 to 1.1 cusecs. Combined they provide a maximum of 4.5 cusecs to irrigated lands.

Channels which tap the nala at high elevations tend to be larger, longer and water greater areas than those originating where it cuts through cultivation. In fact, the four highest channels supply water to 60 percent of the cultivated area, and distribute 51 percent of irrigation flow. Due to their size, importance to agriculture, and the fact that they traverse steep and unstable terrain on slopes above terraces, these channels especially require special attention and skill in channel engineering and maintenance.

A major engineering problem encountered by irrigators involves directing water from the turbulent and variable meltwater nala into channels which requires gentle and consistent discharge. If primary channel flow is not controlled from its source, flooding, channel erosion, slumping of downslope walls, and inequitable allocation result. Control is achieved by merging channel and stream in the following way.

Channels are constructed to traverse gully sides above and almost parallel to the nala itself, but at a more gradual slope. Where the two meet rocks are piled across the nala following the angle of the merging channel, so that some water flows into the channel. Volume of water allowed to enter the irrigation system is controlled by altering the density of this simple dam. Small sluices built into channel walls directly downstream from the junction contribute to additional regulation of flow. Vertical slabs of slatey rock which block sluices can be raised or lowered to regulate water levels in the channels. Both cutoff dams and sluices ensure that water flows through primary channels at the desired level.

Lack of suitable cutoff sites within the upper elevations of cultivation, and the need for gravitational energy to transport water to slopes across the valley necessitates the construction of channels within and across the unstable and erosion-prone nala gully. Slumping hazards within this gully are ameliorated by selective routing of channel paths, and resilient cross-sectional channel design. Irrigators perceive that a channel slope of about three degrees minimizes both erosion and sedimentation of channels. However a greater average slope is needed to transport water from cutoffs as high as 3150 metres to below

2900 metres. Hoparis utilize bedrock outcrops to overcome this problem. They dig channels across debris slopes at about three degrees until bedrock is encountered. Vertical grooves are blasted or chopped down the rock face, allowing water to fall several metres before entering a lower channel. Where outcrops are not available channels are lined with slabs of slate. This helps maintain erosion resistant channels between 10 and 20 degrees. Occasionally long distances of bedrock must be traversed. In these instances channel builders blast flumes into the outcrop at slopes up to twenty degrees. By alternating short distances of carefully located steep flow with long almost horizontal sections, channels avoid potential erosion and traverse the distance from nala to terraces. Villagers accept a certain amount of sedimentation as a necessary evil involved with preventing the much more catastrophic effects of erosion. Sediment can be cleared from channels without major disruption of flow. In addition, a thin layer of fine silt helps prevent saturation through channel walls.

3.3 Response to Geophysical Hazards- Design and construction are only the first steps in the process of supplying water through primary channels. The greatest part of time and effort is spent maintaining channels, and repairing damage caused by mass wasting of channel walls, or obstruction by eroded material from above. Channel failure is caused by: a) erosion of channel beds resulting from rapid flow; b) downwasting of channel banks due to overflow; c) saturation of channel walls caused by extended periods of flow; and d) fracture of channel walls as a result of seismic and nearby dynamite blasting activity.

Channel design minimizes these stresses. In addition vulnerable sections are patrolled regularly, so that flow can be diverted back to the mainstream when signs of potential failure appear. Even so, severe tremors, saturation, and accidental overflow occasionally cause channels to break. When this occurs manpower must be organized to repair the damage quickly (see Section 3.4).

Obstructions caused by activity upslope from channels span the entire frequency/magnitude continuum. Small sand and debris runs are most frequent. Their disruptive effect is virtually eliminated by building drystone walls and digging ditches just upslope from channels. These are cleared periodically without stopping water flow. High magnitude but lower frequency events are the most serious impediment to irrigation. Avalanche triggered debris flows destroy tens and sometimes hundreds of metres of the highest channels almost every winter. Occasional summer landslides have even greater disruptive impacts because they occur during times of high water need.

Dam burst floods are a high magnitude, but extremely low frequency hazard. In 1979 the meltwater nala was blocked by some obstruction, probably avalanche debris, above the highest irrigation channel cutoff. Meltwater forced a tunnel through the dam, so that water flowed into the irrigation system as usual. Hopar villagers were not aware of the obstruction. Melting upstream from the dam exceeded discharge through the dam's opening, and a lake formed. Eventually, the force of the meltwater reservoir burst the dam, causing a major flood and mudflow. Several villagers were killed, 60 to 70 households were left homeless and 30 to 40 hectares of irrigated land were covered with debris. Some of the farmland has not yet been reclaimed. Moreover, the entire irrigation system suffered major disruption; channel cutoffs were washed away, and primary channels were covered with debris. Villagers cannot prevent natural dams in the upper area of their meltwater basin. Gabian baskets were constructed subsequent to the event to contain floodwaters if another damburst occurs. However, it is unlikely that they will work. Villagers can prevent loss of life and property by predicting the occurance of these events. They can diminish losses of agricultural produce by quickly reclaiming land and reconstructing channels and channel cutoffs.

Reconstructing, and sometimes rerouting, sections of channel buried under several metres of rubble is the largest single task villagers face in their efforts to maintain a consistent supply of water to cultivated lands. Large requirements of labour, as well as capital for tools and dynamite, stress community resources, and exceed the organizational capability of several Hopar villages.

3.4 Social Structures- Both equitable water allocation strategies and effective means of organizing labour are necessary at the level of primary channels. The first is achieved smoothly and efficiently according to the traditional system of water rights. Conversely, labour organization has become a major problem in recent decades. Traditional structures of leadership and authority have disintegrated. This inhibits the ability of villages, and the whole community, to maintain and repair vulnerable high channels.

Hopar historically formed a part of the feudal kingdom of Nagyr. Under this system all land belonged to the mir, who granted it to villages. Numbardars (village headmen) in each village acted as the mir's representative, and were responsible for organizing labour to build, repair, and maintain terraces and channels. With feudal authority behind them these leaders could rapidly assemble channel building and repair teams from within the village population. When the damage was beyond the capability of a single village the feudal system's centralized power united teams from several villages.

The feudal authority of Nagyr, and elsewhere in Northern Pakistan, has diminished since partition in 1947, and it is no longer officially recognized by the Pakistani government. This has resulted in many improvements for Hoparis, however it has had the negative effect of removing the traditional chain of authority and social structure without replacing it with another. Numbardars and an advisory council of elders still exist, but without their traditional influence as representatives of the mir. What customary authority they retain now competes with the increasing power of Islamic maulvis, retired army subardars, jeep drivers, shopkeepers and other villagers who have cash resources and access to political and economic influences outside the community. Members of similar age, social, and economic strata support certain leaders and certain objectives. Many of these objectives involve pursuing occupation in the cash sector of the regional economy, rather than traditional subsistence agriculture. The consequent non-integrated community structure has neither the cohesiveness nor the immediately available labour needed to reconstruct large sections of damaged channels. The result has been a gradual disintegration of the highest and most vulnerable sections of the irrigation network.

The history and trend described above is common to many high Karakoram villages. In 1983 the Aga Khan Rural Support Program recognized the situation and began to encourage villages throughout the region to develop self-governing organizations which would pool human, agricultural, and capital resources to the benefit of the combined subsistence/cash economy. AKRSP efforts have had varied success in Hopar, depending mainly upon the willingness of different authority figures to work together. At least three of Hopar's five villages claim to be benefitting from increased organization. That Hopar's highest channel underwent major reconstruction in 1986, bears out these claims. In addition, there is talk of building another large cutoff further upstream. While these initiatives have had success in organizing labour to rebuild they cannot solve the problem of an agricultural work force which is decreasing in size while demand for their labour increases.

Irrigation demand never exceeds about two-thirds of the capacity of primary channels. Therefore, allocation at the inter-village level of these channels is necessary only between May 10th and June 15th, when demand exceeds meltwater supply. For the rest of the irrigation season villages may tap primary channels at any time. Allocation procedures during the period of shortage are summarized below.

PRIMARY CHANNEL WATER ALLOCATION:

Deficit Conditions:

- Early to mid June
- Hununo channel, which waters only alfalfa, is not opened until June 15th. Other channels bypass alfalfa pastures. During this period alfalfa gets some moisture from melting directly upslope. In addition, alfalfa is considered hardier and less important than food crops.
- The five largest of the remaining channels receive water each day at consistent levels throughout daylight hours. These levels vary from day to day depending on daily melting conditions.
- The remaining six channels water very small areas. During periods of water shortage they flow only a few hours each day, or once every several days.
- Handel channel supplies water to three villages, so it flows consistently every day. Villages share the right to tap flow from Handel. Brushal receives water for three days, Ghoshushal for two, and Holshal for three. This timetable continues throughout times of shortage.

- At night all major channels receive low volumes of water. This distributes some water to all households and villages. No field irrigation occurs after sundown. Seven of the primary channels converge in Cycumming, a wooded area at the low, northeast end of the valley. This area is irrigated by residual flow each night.
- Farmers have no water rights apart from their turn as members of a village. Farmers who water out of turn are fined by the village organization. At times, especially in spring, when some channels in a village are not clean or repaired no villager may use water for irrigation.
- In times of shortage water flow is diverted to mill races. This is particularly common during early spring when channels first begin to flow at low levels.

Surplus Conditions:

- Mid June to October
- Main channels flow consistently each day.
- Smaller channels flow as the water is needed.
- Any village may tap water from a primary channel at any time.
- Night flow is used only to irrigate Cycumming, and for household purposes.

4. SECONDARY CHANNELS

4.1 Introduction- The greatest access and control problems of Hopar's irrigation system are dealt with through primary channels. They deliver an equitable and predictable supply of meltwater to the periphery of cultivated lands. Secondary channels distribute that supply within individual villages to all fields. These channels flow through a well developed and geologically stable terrace network, so the hazards which plague primary channels are not significant at this level, except for a long narrow strip at the far east side of cultivation. As a result irrigators are able to develop a secondary system that increases control and access, and improves the quality of water entering fields. The following discussion refers to: a) physical characteristics of the secondary system; b) maintenance and repair; and c) water allocation.

4.2 Physical Characteristics of the Secondary System- The channel network of Hopar's two smallest villages, Holshal and Ghoshushal, is illustrated in detail in Figure 3. This area provides an example of the geophysical and landscape characteristics of Hopar's cultivated area.

Channel patterns are closely related to terrace structure and distribution. Indeed, all channels follow terrace contours and border them on at least two sides. Very intensive terracing is necessary to grade natural slopes up to fifty degrees. In fact, the 40 hectare cultivated area of Holshal and Ghoshushal is dissected by 680 terraces, with an average area of .06 hectares. The resultant agricultural topography averages about five degrees, with maximum cultivated slopes of 20 degrees. It is this intricate terrace pattern which facilitates a dense and relatively stable water distribution network over 27 kilometres in length.

Individual channels flow slowly at shallow slopes with discharges ranging between .001 and 0.1 cusecs. Where water falls between terrace levels flat rocks line the grade to inhibit erosion. Irrigators ensure low velocity by constructing wide, shallow channels with a large perimeter/cross section ratio. This increases sedimentation, and allows maximum radiative and convective warming. In addition, each village has one or two shallow ponds which help to heat water and decrease sediment load. Ponds are used mainly for household purposes, and as low flow reservoirs, but they also release irrigation water downslope. The result of efforts to increase wetted perimeter of channels and ponds, and to decrease velocity of flow is a temperature rise of seven to ten degrees, and a noticeable drop in suspended sediment. Unfortunately, these measures have the negative impact of increasing evaporation from the secondary network. All irrigation water is supplied to Hopar from the west, however east and west-facing slopes as well as the valley bottom are cultivated. The problem this unique situation presents to a gravity-fed irrigation system is overcome by two major channels which follow a circuitous path around the southern curve of the valley. The ridge these channels follow is broken occasionally, so stone, wood and earthen aquaducts have been built. Several other raised channels cut across the valley floor, and maintain the elevation needed to water lower eastern slopes. All main village channels on the south side of the nala converge in Cycumming, a steep wooded area at the north-east end of Hopar. Residual water, rather than being wasted, enters these 40 or so hectares and irrigates the main fruit and wood-producing area. Forested slopes are relatively erosion resistant, and trees can survive large moisture variations, so water is left to flow among the groves at night, and whenever it is available during daylight hours.

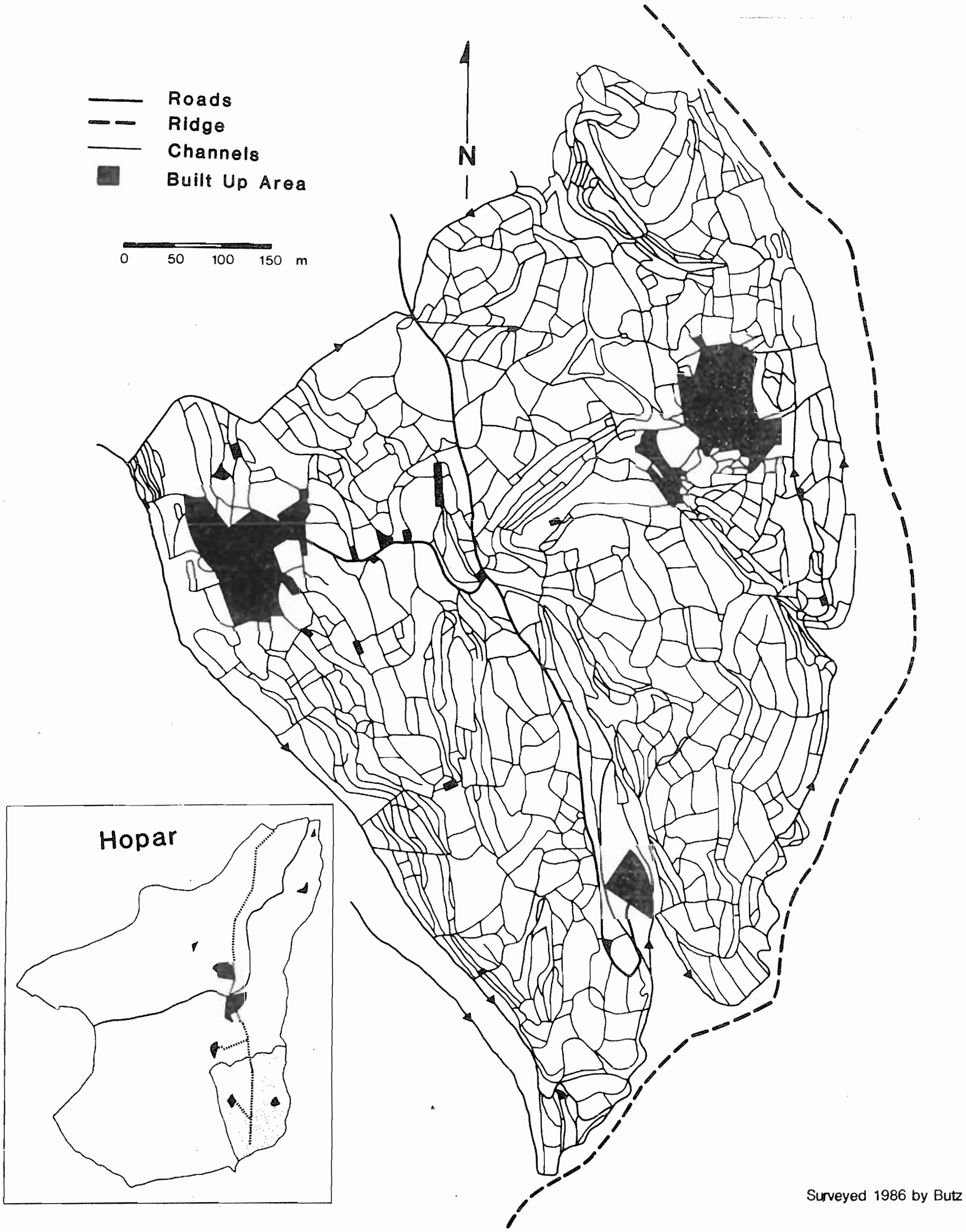


Figure 3

Channel Network in Ghoshushal & Holshal Villages

Surveyed 1986 by Butz

4.3 Repair and Maintenance of Secondary Channels- Maintenance and repair at this level is uncomplicated, both technically and in terms of division of labour. Channels seldom require repair, other than minor reinforcement, due to their location in stable and well developed terrace soils. Maintenance is restricted to regular dredging, and occasional minor reinforcement of walls. Households owning terraces adjacent to channels are responsible for these duties. Specifically, since most channels follow the bottom of terrace walls on the same level as the downslope plots they feed, farmers must maintain sections directly upslope from the land they own. This division of responsibility is easily understood, and the task itself is neither time consuming nor difficult, so neglect and disrepair seldom occurs. When it does, usually in spring, it is because no single villager takes the initiative to clean his channel sections first. As a result entire villages put off dredging indefinitely. Members of villages with effective organizations take advantage of less co-operative villages by arranging to clean all of their channels early, so that they can utilize their share of the early melt, and claim the portion of those villages which are not prepared. No village may claim water until all of their channels have been cleaned.

One or two days each spring is devoted to emptying village ponds of silt and refuse. This is a big job, but villagers appear to look forward to it as a "rite of spring". There was no shortage of men or boys to man shovels and baskets at the pond cleaning we observed. Material hauled from channels and ponds is deposited on channel and terrace walls as a means of reinforcement.

The only significant exception to stability within the secondary channel system are lateral moraines forming a strip along the east side of cultivation. Continual rotational slumping on to the Bualtar Glacier has resulted in the loss of several hectares of land, and at least one major channel. Due to the magnitude of this activity land is, and will continue to be, irrevocably lost. Thus, colonization of new land, and construction of new channels elsewhere is the only way to maintain a constant area of cultivation. Holshal village has begun this process across the Bualtar Glacier.

4.4 Water Allocation- Strategies of water allocation at the village level vary according to availability of supply. Periods of extreme shortage occur in exceptionally cold and cloudy springs, and when calamity disrupts primary channel discharge. Moderate shortage is common most seasons up to early July. Surplus conditions prevail throughout July, August and September. The allocation strategies associated with these supply conditions are outlined below.

SECONDARY CHANNEL WATER ALLOCATION:

Extreme Water Shortage:

- Exceptionally cold and cloudy springs (ie. 1986).
- When slides or channel failure disrupts primary channel discharge.
- All water is used to irrigate wheat crops. Wheat is the community's staple crop, and is vulnerable to drought.

Moderate Water Shortage:

- Each year to mid June.
- Each channel receives a period or portion of water flow corresponding to the area of cropland it supplies.
- Crops are watered on four to seven day rotations, depending on the extent of shortage, so all channels receive water at the same interval.
- Channels stemming from Handel Channel receive water according to individual village rights to Handel water flow.

Water Surplus:

- Mid June to October.
- Channels are fed according to moderate shortage schedule. Any flow above that requirement may be diverted to any channel. Most secondary channels receive water almost continuously during daylight hours.
- Individuals of any village may water out of turn without fear of disapproval, penalty, or

damage to the allocation system.
- Evening flows are used only to irrigate Cycumming, and for household purposes.

5. CROP IRRIGATION

5.1 Introduction- When it finally enters fields water flow retains few of the characteristics of the original melt supply. Temperature is eight or more degrees higher than in the nala, sediment load is much reduced, discharge is low and easily controlled, and timing is predictable. It is important that at this final stage farmers apply water in such a way that these qualities are utilized. Field level water application is described below in terms of timing, volume, and method.

5.2 Timing of Water Application- Villagers state rather vaguely that crops on light soil are irrigated every seven to ten days, and that heavy soils of the valley floor receive water "somewhat less often". Observations from 15 test plots in two of the villages indicate that between May 7th and July 25th 1986, cereal grain crops were irrigated at an interval of six days or less. Some bean and potato fields went seven days between water applications. Almost all Hopar crops received water 15 or more times from early May to late August.

According to field studies by Whiteman (1985, p. 17), many other Karakoram villages apply water at intervals of 10 to 15 days, resulting in relatively fewer irrigations per season. He cites Yasin (2450 m) and Gilgit (1490 m) as examples; they apply water 10 to 15 times, and 8 to 10 times, respectively. Whiteman concludes that the relatively infrequent and consequently high volume applications that are common leach unnecessarily high quantities of nutrients away from plants because as much as two thirds of water input seeps through the rooting profile to subsurface layers. In addition to wasting water and depriving plants of nitrogen and other nutrients, high volume, low-frequency irrigation means that between applications crops must remove 50 to 70 percent of water available to roots (Whiteman, 1985, p. 17). Such moisture depletion can inhibit plant growth and reduce yield.

Several test plots in Hopar were measured for soil moisture. They show that moisture depletion between irrigations is not a significant problem. Even on the fifth day after irrigation, soil moisture at 10 cm exceeded nine percent on light morainic soils. This is probably due to the exceptionally frequent water application practiced in Hopar.

The details of irrigation timing vary as the season progresses and from year to year. In springs of early valley floor melt some fields may be irrigated before cultivation to soften the soil and moisten it in preparation for ploughing and germination of seeds. The opposite occurred in 1986; the valley snow cover melted very late, so upper fields relied entirely on terrace level snowmelt until late May.

Farmers in Hopar always delay irrigation as long as possible after sowing seeds. This year barley was first watered May 7th, a full four weeks after it was sown. Other crops were initially irrigated during the following several weeks, depending on sowing or planting date. Potatoes were planted the first week in May, and consequently first received water in early June. Delaying initial water application serves several purposes:
a) small seedlings avoid contact with cold water until well established;
b) plants grow several centimetres before the clogging effect of sediment deposition is introduced;
c) root development is enhanced by the search for moisture;
d) potential erosion is delayed until roots consolidate topsoil; and
e) available discharge can be diverted to watermills, and wooded areas.

Irrigators are reluctant to apply heavy volumes until June, when plants are mature enough to withstand the stress of cold and siltation. By mid-June demand, supply, and plant hardiness correspond to allow regular intensive irrigation until, one after another, crops begin to ripen.

5.3 Volume- Irrigators inundate fields to a depth of about one centimetre during application. Rough field experiments indicate that about one quarter of application time is spent providing the volume needed for that top centimetre. Since water enters fields at a constant rate about 40 millimetres of water is applied each irrigation. This value varies with infiltration characteristics, and ratio of discharge to demand area. Our estimates are probably somewhat low, because test plots were small, resulting in high discharge per area irrigated. In any case, 40 millimetres per application can be accepted as a rough estimate. This means that at least 650 millimetres of water are applied throughout the growing season. This approximates Whiteman's (1985, p. 17) estimates for single crop areas, however because small amounts are applied more frequently, effectiveness per unit applied is above the norm. Farmers enhance this utility by irrigating early and late in the day when evaporation is low.

5.4 Application Technique- Hopar villagers employ two plot irrigation techniques common throughout the Karakoram region, borderstrip and furrows. Borderstrip irrigation requires the construction of ridges or bunds along the direction of prominent slope. These are handmade before spring sowing or planting. Spacing averages about 2.5 metres apart, but varies according to water supply characteristics. Water flows downslope between bunds, so that irrigation occurs strip by strip across the field. The effect is to irrigate small sections rapidly so that the upper area of a plot does not experience leaching while water flows over it to downslope extremities. Leaching becomes less of a problem with passing time as infiltration rate naturally decreases due to compaction and sedimentation. Consequently, border strips are lengthened periodically. Whiteman reports that strips which initially range from three to five metres, may be increased to over 30 metres by mid July (1985, p. 37).

Furrows are less common than borderstrips on relatively flat, even terrain. However, because they can be dug with little effort by ox-plough they are favored on upper terraces where slopes are steep and topography is uneven. Furrows direct water on an angle diagonal to predominant slope so that crops never receive water directly, but rather absorb it laterally as it seeps downslope. This technique permits less water to reach roots, but has the advantage of protecting crops from siltation. Furrows are adjusted in the same way as border strips to accommodate infiltration rate and slope conditions.

6. CONCLUSIONS

Agriculture in Hopar depends upon successful exploitation of the climatic conditions of two elevation zones. Crops must be grown below 3000 metres due to altitudinal temperature gradients. At the same time, crop moisture requirements are met by snow and icemelt above 3600 metres. Intensive subsistence cropping is possible only because a sophisticated irrigation system transports meltwater from its source above 3600 metres to crops between 2500 and 3000 metres.

Water entering primary channels is cold, dirty and extremely variable in terms of timing and volume of flow. These characteristics impede effective irrigation. At each consecutive level of the channel network their magnitude is reduced, so that when it enters channels, water bears little resemblance to the original meltwater supply. Temperature has risen by at least eight degrees, suspended sediment is substantially lower, timing can be predicted and manipulated within minutes, and volume of flow is between .0001 and .001 cusecs per channel.

This level of control is not achieved through great inputs of western technology, capital, or even exceptionally high labour. Rather it is a result of increasing adaption, manipulation, and regulation of flow as water travels through the system. Hoparis ability to do this is based on thorough understanding of water supply and demand.

Irrigation in Hopar is not flawless. Every spring there is too little water; poor control sometimes results in flooding; occasionally channels break or are blocked and no water flows at all. Even more important than these problems is the fact that subsistence agriculture does not, and cannot support the community of Hopar. The example of increasing high channel disrepair implies that this is the result of disintegration of certain parts of the traditional socio-agricultural system, rather than any inability of that system to deal with geophysical conditions and hazards. The same example also shows that thoughtful development can begin to reverse the trend towards cultural and agricultural disintegration.

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