THE SIGNIFICANCE OF HARDPAN HORIZONS AS THE PRIME FACTOR CONTROLLING THE HYDROLOGY AND LIFE OF SAND COUNTRY: WITH PARTICULAR REFERENCE TO THE FRESHWATER RELATIONS OF THE ST. LUCIA LAKE SYSTEM, ZULULAND

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1 INTRODUCTION

Catchment areas are usually thought of as the familiar mountain and hill slopes at the head and sides of valleys; it is often overlooked that plains are as important as catchments, and are particularly efficient as sponges when covered with a sand mantle fixed by grassland.

Loose, deep sand as typified by the sand plains country of the Kalahari and the Mocambique Plain have a high permeability and very low water retaining capacity, yet there are copious amounts of water or soil moisture not far below the surface. This is due solely to the presence of impermeable horizons at various depths in the sand mantle.

Impermeable horizons have a profound influence on water movement and thus deserve specific attention which they hitherto have not had. The importance and significance of these subsurface horizons has either not been realised, or has been regarded as of no importance.

The importance of these horizons in the freshwater relations of the St. Lucia Lake System can be appreciated from the fact that the largest freshwater lake in southern Africa, Lake Sibayi, is filled solely by local endorheic drainage from sandy grass covered plains. In the same chain of coast lakes is the Kosi Lake System, just north of Lake Sibayi, which is a group of large mostly freshwater lakes maintained only by the local catchments of grass and sedge covered sand plains.

As the hydrology of plainsland is not dominated by gravity the lateral movement of water in the impermeable layers is sensitive to the presence of extraneous factors which alter the water tension away from the direction of flow. Boreholes, drainage canals and tree roots are examples of factors which alter the lateral soil water tension. It is thus obvious that if there were deep sands without any impermeable horizons there would be no chain of coast lakes on the Mocambique Plain and no trees in the Kalahari.

Drought effect is invoked as being the prime factor in drying out country, albeit the rainfall figures do not show much difference from the usual oscillations. Large changes in rainfall amount is certainly the master factor effecting the flow of aquifers, but as we cannot control the climate what then becomes the principal factor? The manner in which the surface of the catchment is treated.

2 BACKGROUND

The following material has been obtained personally from a variety of regions in southern Africa. Seven years experience and study of the north-eastern Zululand (Tongaland) sand plains country, and subsequent detailed studies of sand country ecology in Botswana, South West Africa and the Caprivi Strip. In all these regions the same procedure was adopted to determine the disposition and distribution of subsurface horizons. Soil pits were dug to 15 or 20 ft and the profile examined for texture and mottled zones. In the Western Caprivi Strip a comprehensive collection of sand horizon samples was made and the samples were analysed by the South West Africa branch of the National Institute for Water Research.

The evidence, interpretations and discussions included here are thus obtained from detailed personal knowledge of sand country subtleties over the major sand regions of southern Africa. Much of the material presented here forms an important part of a chapter in the writer's near complete DSc thesis. There is still much that is poorly known, but the essential elements of the dynamic interrelationships are noted below. Further evidence or verification can be demonstrated in the field.

3 HARDPAN HORIZONS

Definition

Hardpan is used here as a collective term for all sub-surface impermeable horizons whether they are indurated or compacted. Hardpan horizons have more than one genesis and vary in morphology. The indurated, cemented types include ferricrete (ouklip), calcrete, silcrete et al. The compacted or claypan horizons are generally the illuviated 'B' horizon. They are formed below the surface but like the cemented types may be exposed at the surface by truncation. Argillic horizons can also be a developmental stage towards the true pan or cemented horizon, and it is thus possible to have all stages in the same area.

In northeastern Zululand there are the following types which effect water movement: argillic horizons, calcrete (calcium carbonate sandstone), ferricrete and in the coast dunesare compacted or cemented layers known as 'dune rock'. In the lower lying areas are often high water-holding peats overlying the pan horizons. Some of these horizons are fossil and bear no relation to present surface configurations.

Distribution

Impermeable horizons occur in all sand regions of the world (and also occur in many other soil types), e.g. Southern Africa, South America (Brazilian savannas), North America and Australia. In southern Africa they are particularly well developed in the Kalahari-type Sands (which extend from the northern Cape to the Congo, and from Angola and South West Africa east to the Transvaal, Rhodesia and Zambia), and in the sands of the Mocambique Plain, of which northeastern Zululand is part.

Characteristics

The hardpan layer acts as a moisture barrier until a relatively high moisture level is built up. This gives a much higher field capacity than that normally encountered in freely drained soils.

Sandy soils have a high infiltration capacity, high total conductivity and high permeability down to the hardpan horizon. When the hardpan horizon becomes waterlogged (saturated) drainage is lateral in this horizon and in the highly porous sand immediately overlying the impermeable layer. The ability of sand to hold moisture is low and water percolation through sand takes place easily and rapidly. The secret to the sand country plainsland is then the distance of the hardpan horizon from the surface.

In some areas several watertables are separated by dry soil or dry cemented layers, the upper water-bearing zone is then called a "perched watertable" which is maintained by rainfall. The preceding degree of saturation is thus important to whether lateral flow is sustained by even lower than mean annual rainfall. The deeper water table or groundwater derives its water indirectly from more remote sources. Because the sand plains catchment type is shallow and variable in distance from the surface, it needs to be of large area to be efficient.

Occurrence and Disposition

Hardpan horizons may be horizontal, undulating or inclined and of varying thickness according to their genesis. They occur in a variety of topographic and drainage situations but may be absent in others. In sandy, undulating country these horizons can be near the surface on the crests of rises, absent or very deep on the slopes and near the surface again in the depressions. This is sometimes due to truncation of a fossil horizon which is left as a remnant in the crests, eroded away from the slopes and deposited in the depressions or reincorporated in the depressions with a deeper fossil horizon. In this case the deeper horizon may be nearly parallel to the surface remnant, but only comes near the surface in depressions. The disposition of impermeable horizons does not necessarily follow the present-day surface undulations. However, one fairly constant feature of hardpan layers in sandy country is their near-surface occurrence on the crests of rises. This feature is made conspicuous by the presence of different or denser and taller woody vegetation in these situations.

Their control of hydrology and function as aquifers

Sand plains country is seldom flat but is composed of a complex or simple surface topography with undulations of greater or lesser amplitude. Where all the seasons rainfall is intercepted by hardpan horizons lateral flow or seepage takes place towards lower ground (in the absence of extraneous factors noted in 1 above). Hydrology in this situation is a near surface phenomenon and is composed of two main types: (i) exhorheic drainage, and (ii) endorheic drainage. An example of the first is the Kosi Lake System and of the latter Lake Sibayi is a grand example, but myriads of smaller ones are typical of all the sands. What is not known is whether these smaller ones contribute water vertically to the deeper hardpan layers. The smaller endorheic pans and marshes are generally isolated but some may temporally link during exceptionally high rainfalls. Lateral flow of water is dominant and the build up of high soil moisture is due to the high water holding capacity of the impervious layers.

Because of this feature, the impervious hardpans can maintain lateral water flow or movement even during droughts as there is sufficient soil moisture in the impermeable layer for rapid saturation to occur in times of less than mean annual rainfall. A study of the other coast lakes north and south of Lake St. Lucia, and the strong flow of the drainage on the eastern and north-eastern side of the Lake (eg. Mbazwane Stream) show the impervious layers of otherwise loose sand country to be highly efficient aquifers. In the worst droughts experienced in northeastern Zululand many of these drainage lines and swamp forest covered courses are dry on the surface, but dig below the surface and one will find that there remains a strong flow to lower ground, as also indicated by the continuance of the endflows.

The strong-flowing Mbazwane Stream is a perfect example of the efficiency of these hardpan horizons as aquifers maintaining a sustained flow of water. In deep sands without impermeable horizons there would be no hydrology to speak of, the total seasons rainfall would percolate to a certain depth and then dry out and be lost in the dry season (see following section).

Their control of plant community distribution and physiognomy

The distance of the hardpan horizon from the sand surface, and soil aeration (aerobic and anaerobic conditions), which is a function of topography, are the most important combinations of factors governing the spatial distribution of woody cover and grasslands.

The nearer the hardpan horizon to the surface the greater its ability to absorb the total annual rainfall and thus these are the sites, depending on the topography, where either the densest type of woody vegetation occurs, or where drainage lines occur. To be efficient the hardpan horizon must not be at the surface as then there is a tremendous loss of rainwater by sheetwash as in the Mopane or Tamboti clayey soils.

The widely separated sand regions of the Mocambique Plain and the Kalahari, whilst occurring in different rainfall regimes, show many similarities in the spatial distribution of plant communities. Dense stands of trees occur chiefly on the crests of rises. In northeastern Zululand these situations are typically occupied by Dry Forest and in the Kalahari by *Acacia giraffae* Woodland. These closed woody plant communities occur on sand overlying a hardpan horizon near the surface which intercepts most of the seasons rainfall but does not become waterlogged, i.e. remains aerobic. The closed communities meet the open savanna abruptly, deep rooted tree savanna in northeastern Zululand and shrub savanna in the Kalahari. In both regions this abrupt change is due primarily to the termination of the hardpan horizon giving place to either horizonless sand or to a much deeper hardpan layer.

The Kalahari shrub savanna physiognomy is formed chiefly by the absence of a hardpan horizon within reach of the seasonal rainfall. There is adequate soil moisture for periods during the summer growing season, but with the onset of the dry season there is not sufficient soil moisture and the woody plants die back to ground level and coppice again the following year (many are normally of tree growth form). To add to this master control of the shrub physiognomy are other affecting factors, chiefly fire and frost. The lower parts of the sand country are then occupied by grasslands or sedge if there is sufficient soil moisture. In northeastern Zululand where there is surface flow of water in drainage lines the cover is swamp forest. Swamp forest rarely ever occurs on the most important catchments of sand country aquifers as these anaerobic sites are occupied by grass and sedge vegetation. Dune forest occurs on the well drained sites of the highest rainfall zone of the northeastern Zululand plain, on coast dunes which also receive rain in winter.

Sand country indigenous woody plants have two well developed root systems. A shallow lateral system which occupies the surface 6 inches where the only humus and plant nutrients occur. And a deep tap root which is primarily for water. The lateral roots are also important for intercepting light rains. This is the typical situation where the hardpan horizon is between 15 and 20 foot or more, or where porous indurated hardpan is exposed at the surface. In lower rainfall zones where the hardpan horizon is beyond 10 to 15 ft deep the cover is shrubland or grassland. In northeastern Zululand where the hardpan layer is near the surface in well drained sites the Dry Forest woody cover have well developed lateral root systems which occupy the hardpan layer, and poorly developed or no deep roots. The argillic type illuviated horizon provides both plant nutrients and moisture.

The effect of plant cover type on the water balance of the hardpan horizons

Large quantities of water are necessary for the metabolic requirements of growing plants. A given quantity of water in the soil is moved from the hydrosphere to the atmosphere far faster through the metabolic energy of plants than would be the case from direct evaporation. The tremendous amounts of water transpired by plants is a well known fact and numerous quantitative examples can be found in university textbooks. A typical example (from Temperate lands) reads: "A single corn plant (in Kansas) between May 5 and September 8 transpired 54 gallons of water. An acre of such plants (6000 plants) would transpire during the season 324,000 gallons of water, which is equivalent to a sheet of water 11 inches deep over the entire acre. It has been estimated that an acre of red maple trees, growing in soil with ample moisture, may lose in a growing season an amount of water sufficient to cover the acre with 28 inches of water..... Of the total quantity of water absorbed by the roots of plants as much as 98% of it escapes from the plant by transpiration."

The important point for this discussion is that in the sand country the woody cover is in direct contact with the hardpan water tables whereas the grassland is not, except where these layers are close to the surface. The hardpan horizons have available a large water storage capacity but are sensitive to use by dense woody plant cover which creates a multiplicity of local tensions and leave little for lateral movement.

When the sandy soils and their impermeable layers are near saturation there is easier water movement laterally or for use by woody plants, but as the soil water becomes less the forces necessary to remove a unit amount of soil water become great. The tension of soil water is greater when there is a woody cover with its roots in the hardpan horizon, whose water does not continue to flow laterally as the balance of water tension is moved from the lateral to an upward or localised tension around the root zones of each woody plant.

The woody plant cover is self-preserving in the natural state where the panhorizon is kept from being waterlogged by the transpiration of the cover. In the lower rainfall zone on the western side of the Plain (eg. False Bay) woody components of Dry Forest or Thicket may approach the wilting coefficient and this seems to act as a trigger to deciduousness in many species. At the same time the same species on the eastern higher rainfall side of the Plain remain evergreen and are even to be found in flower and fruit as the more perennial nature of the coast rains keeps the hardpan horizons perennially moist. This is why the natural woody cover is seldom radically affected by drought in this area as compared with Botswana and South West Africa. In the latter areas seven or ten years of more than mean annual rainfall allows a dense woody cover to dominate, but if this followed by the same length of time of less than mean annual rainfall large patches of woody plants die and this seems to restore the balance between density of woody cover and the available soil moisture of the hardpan horizons.

Thicket is composed of a dense and often impenetrable aggregation of mostly savanna elements, and is the typical mature or submature cover on disused cultivation sites or in areas that have been subject to heavy overgrazing by ungulates. Shifting cultivation in the sand country is chiefly on the compact sands or where the argillic horizon is close to the surface. Cultivation compacts the soil and extends the sites suitable for dense woody plant invasion with cessation of cultivation. There are many examples in northeastern Zululand where overstocking and shifting cultivation has resulted in dense and extensive thorn thicket and the loss of once perennial springs and streams. The Ndumu area in the lowest rainfall zone of the Plain can provide many examples of this phenomenon, as can the Nibela and Ndhlozi Peninsulas of Lake St. Lucia. Remove this secondary thicket and replace it with grass or other herbaceous cover and the springs are usually restored, and the small endorheic pans become perennial or near perennial again.

These successional processes leading to cessation or dimunition of freshwater springs and streams are well documented from all over Africa, particularly in the areas subjected to long shifting cultivation, overstocking and burning in the beninning of the dry season. Field ecologists of repute, such as Professor J.F.V. Phillips who has an intimate knowledge of most parts of Africa, have recorded this nonclimatic phenomenon across the continent.

The classic example of the subtlety of the water relations of the hardpan horizons, and the delicate balance there is between the type of plant cover and soil aeration is portrayed by an episode on the western boundary of False Bay Park (St. Lucia Lake System).

On the western boundary of False Bay are strips of Dry Forest interspersed with tall tree savanna and thickets. The same cover once extended west to the Enseleni River. Sand country on the crest, and on the sides the hardpan horizon emerging above the Cretaceous on the slopes down to the False Bay shoreline. There was a pineapple boom and the ensuing scramble to make money quickly resulted in the near complete clearance of the country immediately west of the park fence. The cleared sand country was planted with pineapples. Like grassland the pineapple cover uses the surface horizon of the soil and would only be in contact with the argillic horizon where it was shallow. In two summers streams and springs began to flow on the park side of the boundary. These springs and surface flows had not occurred for at least 20 years or more, and they followed the faint depressions of a past drainage! This happened because the hardpan horizon was able to become fully saturated in the absence of a dense woody cover and lateral flow began which resulted in the restitution of springs and oozes, and killed sectors of the Dry Forest on the park side. This is the driest rainfall zone of the Plain. How important then are the hardpan horizons on the eastern high rainfall zone of the Plain.

The story from False Bay illustrates several points: it emphasizes the keystone position of the hard-pan soil water relations in sand country. It exemplifies the danger of drawing definite conclusions from visiting studies on the one hand, and on the other the danger in not using field controls in a study, as one uses controls for laboratory experiments. Only from comparative field research can the essential elements of a system's functioning be obtained. Ecology is like a chemical reaction, change one key part of the interrelationship and it can alter the whole profoundly. Ecological processes are cyclical.

The subsurface compacted horizons in the sands have been dismissed as of no importance, and the Cretaceous has been brought into the story despite the findings of the geologist and the significance of the borehole findings where aquifers were shown to be present between 30 and 50 ft below the surface. The covering of the whole countryside around Lake St. Lucia with exotic timber trees is thus shown to be the principal reason for the cessation or lessening of the perennial freshwater aquifers around the Lake.

The vegetation type which uses only the surface of the sand mantle is grassland, and it is only under grassland that a very high field capacity can be attained and maintained. This provides a perennial lateral movement of water which collectively gives rise to a copious flow as well exemplified by the Mbazwane Stream.

4. THE ST. LUCIA LAKE SYSTEM

Rainfall zonation and characteristics

Details on this subject are covered in the Lake Commission Publication but certain features need to be emphasized. Rainfall in the Lake System occurs in longitudinal zones with the highest isohyets over the coast dune range in the east and the lowest on the west of the Plain. The rainfall decreases suddenly over a short distance of about 10 miles away from the coast dune range.

Away from the eastern high rainfall zone, rainfall is markedly seasonal and is confined to the summer months. Typically this zone experiences summer droughts in addition to the usual winter dry season. By contrast, the eastern high rainfall zone is not markedly seasonal and receives rain throughout the year with a maximum in the summer months. This feature is particularly important in maintaining the strong water flow in the aquifers of the eastern and northeastern sectors (Mbazwane catchment) of the Lake System.

The local catchments

As described above, the hydrology of the northeastern Zululand sand country is dominated by lateral drainage feeding two main processes, exhorheic and endorheic drainage, between which there is probably little to no water movement. In some places a third type, areic drainage, occurs where solution cavities in the Cretaceous Strata receive water from the contact zone with the sand mantle's hardpan layers.

Where woody plant tap-roots penetrate hardpan layers there is not necessarily any water loss to lower levels as most of these horizons are self-sealing. The self-sealing ability of hardpan horizons was well demonstrated in the early days of the Forestry Department at Mbazwane, where pans were dynamited in an attempt to drain them for tree planting.

The streams, springs, pans and marshes on the Nibela and Ndhlozi Peninsulas and the eastern sector were almost all of a perennial type but many of the weaker flows on the Peninsula margins stopped when scrub and thicket invaded the extensive areas of shifting cultivation. The great aridification however is due to the afforestation. The Forestry Department admit that afforestation has been a contributary factor (Dr. Nänni pers. com. with I.C. Player). Prior to afforestation, what was the spatial distribution of natural woody cover and grassland? And what did it indicate? Prior to afforestation only the margins of the Ndhlozi peninsula supported remnant forest, thicket and savanna woodland, and the entire central part was, except for a few high ground islands, entirely covered by grassland and sedge. The indigenous woody cover was confined to the well aerated sites, the remainder was waterlogged or liable to long periods of saturation. As the woody cover was confined to the peninsula margins it had little to do with diminishing the flow of streams entering the Lake because they occurred at the end point of the drainage. When droughts occurred the weaker aquifers became oozes or dried temporarily, but the majority maintained their water flow. Old natives born and bred on the Ndhlozi and Nibela Peninsulas can provide much valuable information on this subject.

The Lake cannot exist on its own, as most of the exotic rivers (except the Hluhluwe River) are seasonal or near seasonal. Only one thing enabled the Lake's ecosystems to survive in the dry seasons, the perennial freshwater from local drainage particularly that from the high rainfall zone of the eastern and northeastern sectors.

The forested coast dune ranges in this eastern sector are important and conspicuous catchments of the higher rainfall belt associated with the dune ranges and the land-sea junction. Forest occurs on the dunes because of two prime factors, they are well watered but at the same time well aerated. The plains below are waterlogged grasslands which maintain perennial streams into the Lake even through the worst drought periods. The natural tree community on the lower parts of the streams, swamp forest, are of little significance in using up more water than exotics because they occur below all the source areas of catchments which are covered in grass and sedge (for further examples see the Kosi Lake System and Lake Sibayi). It is precisely these open 'flat' catchments where the exotic plantations have been established and aided by the cutting of drainage canals. In fact pine species which can live in or near anaerobic waterlogged conditions has been used by the Forestry Department to dry out the marshes and hardpan layers further for the purpose of planting the more desirable timber trees. Forestry Department show well their appreciation of the use of ecological plant succession amongst exotics.

The great variety of natural life

The St. Lucia Lake System is the richest lake system in southern Africa (including Mocambique) primarily because it is a natural system based on a mud substrate. The other large lakes of southern Africa such as Lake Sibayi and the Kosi Lakes are by contrast depauperate in life as their systems are based on a sand substrate. This is the fundamental principle governing the conspicuous differences in abundance and variety of natural life between these two lake types.

But in addition St. Lucia Lake is surrounded by acidland communities, - a junction of two systems. The Lake System also has a multiplicity of communities, and these provide a mosaic of edges. Edge effect is an important factor in its influence on the abundance and variety of life at the overlap or interface between different communities. This variety of ecosystems is brought about by a number of factors which include (with those above): e.g. (i) it is the zone of contact and overlap between the tropical and temperate life divisions, (ii) the distribution and vertical disposition of the hardpan horizons, (iii) a meeting of marine and freshwater biomes, and (iv) the narrowing of the Mocambique Plain in the St. Lucia area, telescoping the more widely separated biotas of the north to occupy the available ground adjacent to the Lake.

5 CONCLUSIONS

For Lake St. Lucia to survive it is a prerequisite that the whole local catchment area must be included in the natural reserve. A half mile broad strip around the edge of the Lake is convenient on a map, ludicrous and dangerous as the whole system of the Lake is completely dependant on how somebody else uses the catchment. The large exotic rivers are indispensable for refreshing the Lake with flood water and silt, but at the height of the dry season and during droughts it is the local catchments which save the Lake System. Without the exotic plantations the whole system is able to adjust to the vagaries of the rainfall.

A unique natural system like Lake St. Lucia can never be recalled or remade once lost, its loss would be irreparable to the uniqueness of South Africa. Man can plant exotic plantations where he pleases if the trees basic requirements are met, but he cannot remake an entire natural ecosystem.

After the completion of the Lake Commission's investigations and their recommendations to our Government there appears to be a resurgance of arguments and counter-arguments or new projects. Amongst all said and done there is one final question which every person involved in the St. Lucia Lake problem must ask themselves. Is the Lake one of the last unique wild areas left in our country, is it a worthy example of the uniqueness of our land? If the answer is no, then Forestry Department must plant to the edge of the Lake and the Lake muds must be further silted by removal of the papyrus-sieve of the Mkuze River mouth. In this way rice, sugar cane and vegetables such as carrots will be able to be produced here. If the answer is yes, it is one of the finest wonders left of our country comparable in uniqueness to the Cape Mountains and their flora and fauna, then all individuals, no matter what department or side they represent must be man enough to see beyond minutiae and say 'I am a South African, and this place is unique, we stand together and plan to keep the St. Lucia Lake System wild for all time as one of our country's natural wonders.'

It comes to a personal decision of yes or no. Only when this major decision is made can we get down to ironing out the lesser problems, as lesser problems they are. Most of the problems are made simply by being bogged down in minutiae or intra and inter-departmental 'antis' and specializations without the essential elements ever being discerned.

The Minister for Forestry has used the phrase,

"... only a much bolder approach will solve the problem on a long term basis." It is submitted that the evidence provided in this note on the essential keystones of life in sand country makes the conclusion that the bold approach to saving Lake St. Lucia is to include all the local catchment area (from Sordwana to the Estuary and from the seashore to False Bay) as part of the natural reserve.

A decision must be made now as there can be no compromise or barter of pieces of ground here and there in such a small area, the whole local catchment system of the Lake must be saved. To look for alternative water sources is a negative approach and only delays a decision or the evil day when the whole area becomes lifeless and criss-crossed with pipelines.

If our Government decide to keep this Lake System as of lasting value to the peoples and country of South Africa, it will be the task of a wildlife conservation department to ensure that the water balance is not lost again by indigenous woody plant invasion.

There is an urgent need for land classification studies as the present piece-meal development of the land by departmental projects lessens the productivity and variety of the land and defaces large areas quite unnecessarily. Conservation of natural resources, far from inhibiting the development of a country, substantially assists towards that end. It is possible for all parties to be satisfied if the land is correctly apportioned on an ecological basis. Unless all land managing agencies join in common effort to draw up a plan, the best form of land usage will never be realised.

APPENDIX

(1) For an excerpt topical to the St. Lucia problem see FUNDAMENTALS OF ECOLOGY by E.P. ODUM (1959) pp.422 - 423

(2) Refer also to FUTURE ENVIRONMENTS OF NORTH AMERICA edited by F. FRASER DARLING and J.P. MILTON (1966) 767 pages: The Conservation Foundation. (Being the Conference papers and discussions on the subject of the transformation of a continent).

This is one of the most remarkable and important books of our time dealing with the effect of man on his environment and how he can alter the present pattern of environmental use to obtain one of "order and diversity, health and beauty".

/HC

30th April, 1969