Groundwater Levels Are Critical to the Success of Prescribed Burns

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ABSTRACT

Historically, frequent lightning-ignited fires played an important role in sustaining fire-adapted natural plant communities in the Southeastern Coastal Plain Physiographic Province (SCP). The frequency of the fires maintained pulses of readily-available nutrients; suppressed less fire-limiting, competing species; and insured burns of relatively low intensity by reducing fuel. Longleaf pine (*Pinus palustris*) forests, wet prairies, pondcypress (*Taxodium ascendens*) wetlands and cut-throat (*Panicum abscissum*) seeps are examples of natural communities which appear to rely on periodic fires to recycle limited nutrient supplies, maintain safe fuel loads and reduce competition from aggressive woody species. Extensive landscape changes, urbanization and suppression of these periodic, low-intensity fires threaten the continued existence of these natural communities. Prescribed burning has become essential to maintain these fire-adapted communities.

Weather conditions were the controlling factors in successful fire management under historic conditions. Scheduling of prescribed burns typically still is dictated by weather conditions, with no consideration to groundwater levels. Unfortunately, anthropogenic activities have lowered water tables below levels associated with natural drought cycles in many areas of the SCP. These artificially lowered levels have major implications for prescribed burns conducted near wetlands. Therefore, anthropogenic alterations of watertable levels should be a critical factor in the decision of when and how to execute a prescribed burn if wetlands are involved. Recommendations are provided that will improve the success of, and minimize damage from, prescribed burning in the SCP.

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INTRODUCTION

Prescribed fire has been used widely to manage commercial stands of timber and public pinelands in the southern United States with relatively predictable and successful results (e.g., improved habitat and food sources for target animal species; reduction of competitive plant species; apparent release of limiting nutrients), particularly when prescribed burns mimic natural burns (Carter *et al.* 1973; Komarek 1971; Myers and Ewel 1990; Stevenson 1993; Stone 1971; Wade and Lunsford 1989; Wells 1971). Unfortunately, the effects of prescribed burns on natural herbaceous and forested wetlands interspersed throughout these pinelands are not understood as thoroughly as the responses in upland communities. Severe adverse effects of both prescribed burns and natural fires on wetlands in central Florida recently have been documented in areas where groundwater levels have been lowered due to anthropogenic activities (Rochow 1994). Wetlands in both the lower and upper Southeastern Coastal Plain Physiographic Province (SCP) appear to be subjected to anthropogenic perturbations of groundwater levels (Bacchus 1994).

Artificial lowering of water tables below levels associated with natural drought cycles have major implications for prescribed burns conducted near wetlands. As a result, wetlands throughout the SCP may be vulnerable to destruction from prescribed burns due to altered hydroperiods.

Weather conditions (primarily rainfall, with consideration of wind velocity and relative humidity) currently are the main focus in predicting burn acreages from wildfires and in setting prescribed burn criteria and schedules (Barnett 1991; Brenner 1991; Main and Haines 1983; Simard *et al.* 1985a; Simard *et al.* 1985b; Simard *et al.* 1989; Turner ND; Wade and Lunsford 1989). This approach may be adequate in areas where groundwater levels have not been altered. However, abnormally low watertable levels can persist during periods of normal and excessive rainfall in areas subjected to various anthropogenic activities. A situation of this nature will lead to underestimations in predictions of areas subjected to wildfire. In areas where activities in adjacent uplands have resulted in significant reductions in groundwater levels of associated wetlands, the weather-based approach could result in significant destruction of organic hydric soils and wetland vegetation.

Rainfall events which would have ensured adequate soil moisture under unaltered groundwater conditions may be inadequate to protect the root zones of the wetland vegetation and to prevent ignition of organic soils during prescribed burns and wildfires. Consequently, consideration of weather conditions as the primary abiotic factor governing an ecosystem's response to fire is too narrow and should be expanded to encompass the hydrologic conditions of a site.

The matter is complicated when indicators of stress which are detected by alert field personnel in wetlands subjected to artificial reductions in the water table often are mistakenly attributed to recent rainfall patterns and are termed "drought-stress" responses. Use of the term "drought-stress" is overly restrictive and erroneously infers that the plants are responding to reduced rainfall rather than reduced availability of ground water. Use of the term "drought-stress" should be abandoned in favor of the term "water-stress". Examples of anthropogenic reductions in the water table which have resulted in water-stress in Florida are discussed later in the paper. Similar responses have been observed by the author throughout the lower coastal plain of Georgia, Louisiana and North Carolina, and in the upper coastal plain of South Carolina.

(NOTE: The terms "ground water" and "water table" appear as two words, one word and hyphenated in the technical literature. This paper will follow the convention of using the terms as two words when used as a noun and one word when used as an adjective. Nomenclature for plant species referenced in this paper follows Godfrey (1988) for *Taxodium* Godfrey (1988) and Radford *et al.* (1983) for other woody species and Godfrey and Wooten (1979, 1981) for herbaceous species, except for *Panicum abscissum,* which follows Wunderlin (1982)).

The purposes of this paper are to:

1. provide support for the assumption that some wetland communities in the SCP, including an endemic natural wetland community in south-central Florida, appear to be adapted to, and rely on, prescribed fire for continued existence;
2. discuss various activities conducted in uplands, including surface excavations and subsurface drainage without surface excavations, which are capable of lowering groundwater levels in adjacent wetlands;
3. briefly describe the potential damage caused to wetlands with altered hydroperiods which are subjected to prescribed burns; and,
4. recommend revisions to the present approach to prescribed burning for amelioration of wetland-related losses.

FIRE-ADAPTED WETLANDS

Florida contains extensive areas of wetlands which receive a significant proportion of water through lateral flow of shallow ground water. Ground water of this nature is known as seepage. These seepage wetlands are discussed briefly in the Guide to the Natural Communities of Florida (FNAI and FDNR 1990). Examples of forested seepage wetlands are loblolly bay (*Gordonia lasianthus*) swamps, also known as baygalls, seepage swamps, and bayheads. In undisturbed areas, these wetlands commonly are surrounded by a zone of pond pine (*Pinus serotina*). They may be isolated vegetatively (i.e., no connection to water bodies via wetland vegetation, although sheetflow connections may exist during periods of high water) from other wetlands, or directly connected to bodies of water, serving as headwater systems for streams or throughflow systems for ponds and lakes.

Herbaceous and shrub seepage wetlands, with hydrology similar to forested seepage wetlands, include bogs, seeps (FNAI and FDNR 1990) and wet prairies. Probably the least known of these types of wetlands is the cut-throat seep, which is dominated by cut-throat grass (*Panicum abscissum*). Cut-throat seeps are endemic to south-central Florida, with the majority of occurrences confined to Highlands and Polk Counties (Bacchus 1992). The typical groundwater flow pattern of seepage wetlands is exemplified by the conceptual model for cut-throat seeps shown in Figure 1a, which portrays the isolated and through-flow characteristics mentioned above.

The shaded K_2 zone in Figure 1 generally is represented by a layer of clay which is overlain by highly permeable sands (e.g., sandhills). For this reason, these wetlands often are referred to as "perched". When infiltrating water from rains reaches this zone of lower permeability, lateral flow is initiated, generally in a direction toward the wetland.

Cut-throat seeps, in addition to wet prairies, pond pine and pond cypress (*Taxodium ascendens*) wetlands appear to operate under this hydrologic regime and generally benefit from periodic fires (Bacchus 1992; Carter *et al.* 1973; Ewel and Mitsch 1978; Myers and Ewel 1990). Exceptions have been noted in wetlands with apparent anthropogenic alteration of the hydroperiod (Bacchus in press; Bacchus unpub.). For example, Figure

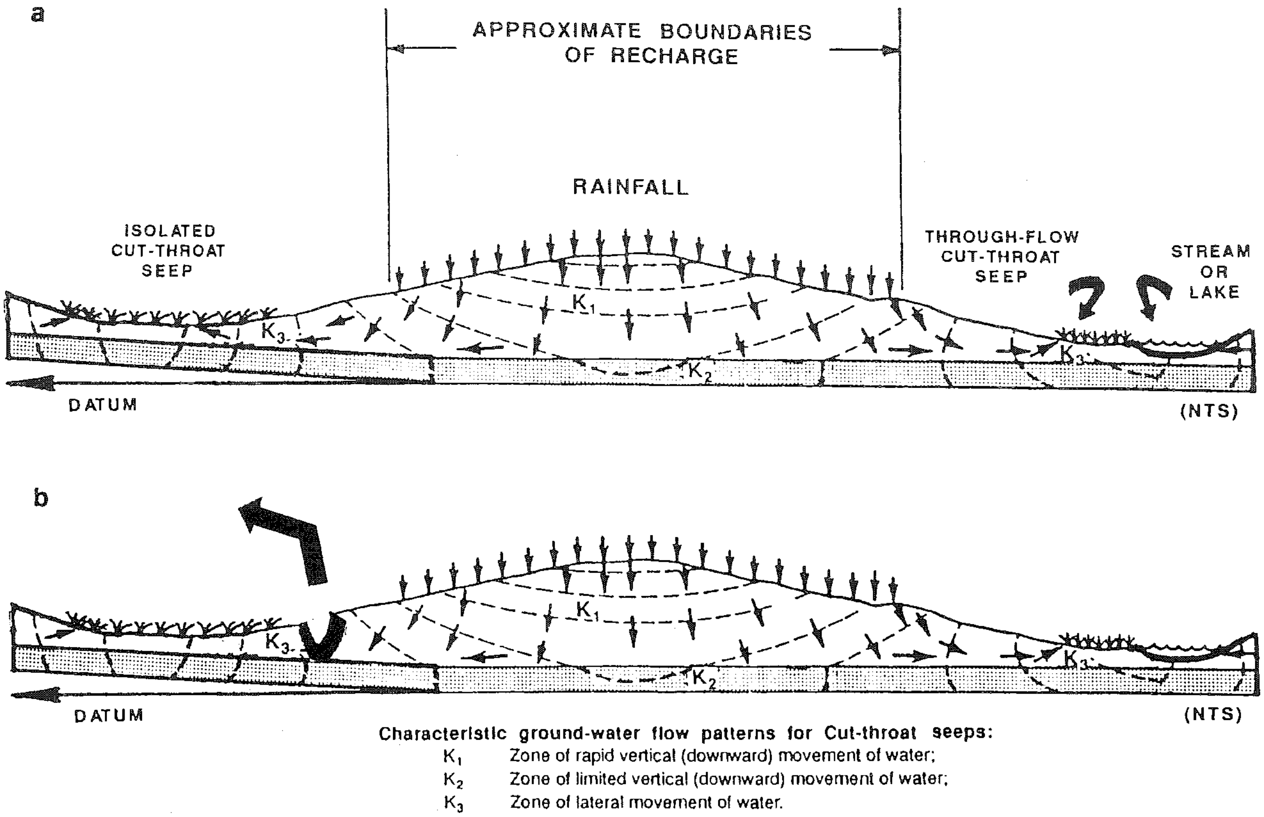

Fig. 1. Conceptual hydrologic model of a cut-throat (*Panicum abscissum*) seep in (a) an unaltered state, and (b) with perimeter ditching which intercepts shallow, ground water flowing laterally into the wetland (Bacchus 1992, reproduced with the permission of the Central Florida Regional Planning Council).

2a shows the tip of a cut-throat seep in Highlands County, Florida, with Virginia chain fern (*Woodwardia virginica*) in the foreground and a shrub thicket in the background. The open area of cut-throat grass (cut-throat panicum), which extends to the left of the photograph, resulted from a patchy burn. Figure 2b shows the interior of the same shrub thicket, a few meters from the previous photo point. Here gallberry (*Ilex glabra*) and scattered wax myrtle (*Myrica cerifera*) have overgrown the now spindly cut-throat grass beneath. Soils (sample from upper horizon shown in Fig. 2b) and relative elevation appeared similar at the two locations (Lewis Carter pers. comm.). This observation supports the belief that cut-throat grass requires periodic fires to exclude shrubs which compete for sunlight and, probably, nutrients. Frost (pers. comm.) reports that the natural frequency of historic fires was one to three years throughout the portion of the SCP which includes the entire range of cut-throat seeps and closely approximates the range of pondcypress; the range of baldcypress, *T. distichum,* extends beyond that of pondcypress. A fire frequency of this nature would be sufficient to exclude shrubs from these seeps and other fire-adapted wetlands.

Additional evidence of the importance of fire to the vigor of cut-throat grass is demonstrated by a series of photographs taken by the author on 25 April 1991, on the same roll of film (Fig. 3a–c). Note the general chlorotic appearance of the cut-throat grass and the encroaching wax myrtle shrubs in the upper photograph. The cut-throat grass in the middle photograph is lush and dark green, presumably from the recent release of nutrients in the ash following the burn. The cut-throat grass in the bottom photograph also has a deep green color. However, the plants in Figure 3c are stunted, despite the fact that the burn at this site was conducted at a similar time of year as the burn for the stand shown in Figure 3b. Considering the similar length of time for regrowth, the stunted nature of the plants at the third site may be attributed to the prolonged history of cattle grazing, which does not occur at the other two sites. During an evaluation of all reported cut-throat seep communities, similar stunted stands were not observed at ungrazed sites. Prolonged grazing of a plant unadapted to such pressures could deplete the carbohydrate reserves in these plants, resulting in a stunted growth form.

Figure 4 provides a closer view of representative clumps of cut-throat grass from these three sites. Note again the variation in growth form and apparent vigor between the spindly, chlorotic plants from the unburned cut-throat seep of Arbuckle State Park (left); the robust,

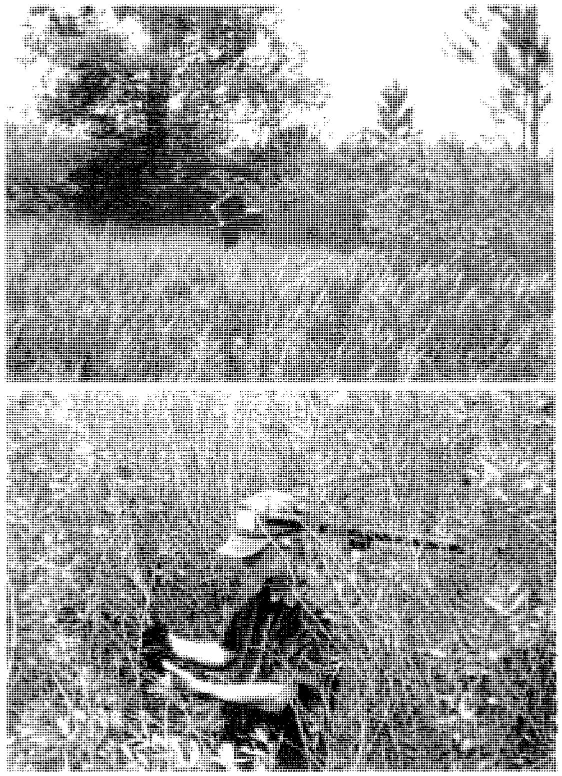

Fig. 2. Cut-throat (*Panicum abscissum*) seep, Highlands County, FL, (a) in full sun, without competition from shrubs, and; (b) overgrown by gallberry (*Ilex glabra*) and wax myrtle (*Myrica cerifera*). Photographs are reproduced with the permission of the Central Florida Regional Planning Council (Bacchus 1992).

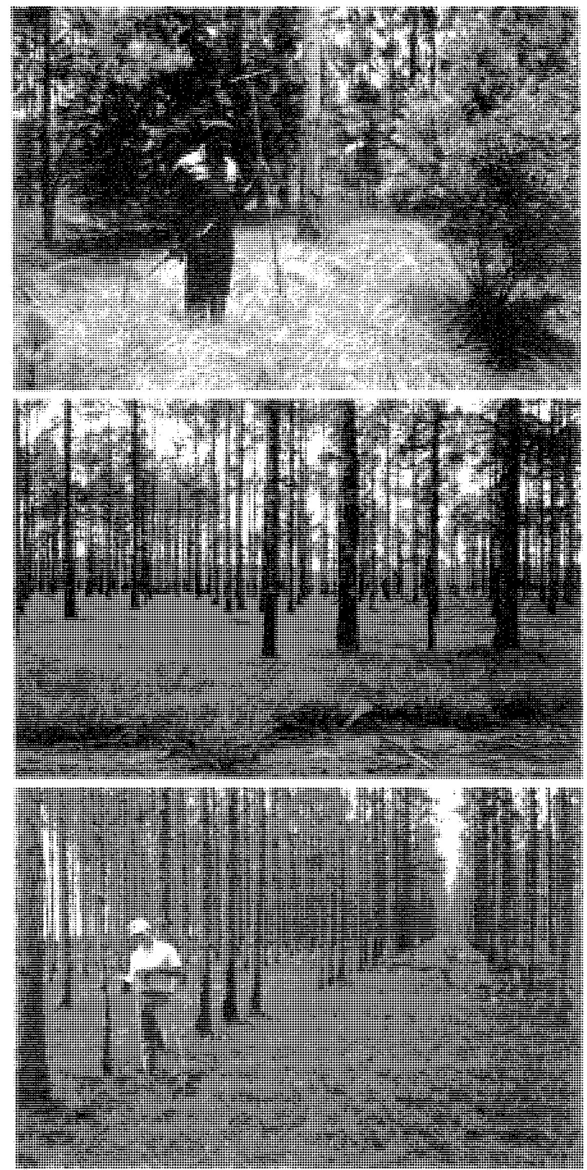

Fig. 3. Variation in apparent vigor of cut-throat panicum (*Panicum abscissum*) in (a) an unburned cut-throat seep in Arbuckle State Park, south Polk County, FL; (b) an adjacent cut-throat seep in Arbuckle State Forest, burned in March 1991; and (c) a nearby cut-throat seep in the Avon Park Air Force Range, north Highlands County, FL, burned in February 1991. Photographs are reproduced with the permission of the Central Florida Regional Planning Council (Bacchus 1992).

dark green plants from an adjacent cut-throat seep in Arbuckle State Forest, which received a prescribed burn in March 1991 (center); and the stunted plants from the Avon Park Air Force Range, which received a prescribed burn in February 1991 (right), but which have been subjected to a lengthy history of cattle grazing. Also note the fertile culm (arrow) produced by the cut-throat grass from the state forest. The production of seed was observed throughout the state forest site, while no flower or seed production was observed associated with the cut-throat seeps from the other sites. This observation suggests that some limiting/unavailable nutrients are liberated following a fire. It also suggests that reduction in vigor due to grazing may override the benefits obtained by prescribed burning.

A similar response of production to fertile culms by the grass, *Spartina pectinata,* in Kansas was observed by Johnson and Knapp (pers. comm.) following burns. Although they speculated the response was due to increased soil temperatures following removal of accumulated litter, this response also could be related to increased available nutrients.

Lugo (pers. comm.) views the soil as a vast reservoir of nutrients. However, Christensen (pers. comm.) shows that nutrients such as phosphorus may be limiting and that soil microbes exert a strong influence on the availability of nutrients from the "reservoir". Abiotic factors such as pH also are known to affect a plant's ability to utilize nutrients in the soil (Pratt 1970), particularly under conditions of low pH. The interstitial pH of the soil in pond cypress wetlands, an apparent fire-adapted community, commonly is in the range of 4.5 (Miller *et al.* 1993; Bacchus unpublished data).

Despite the absence of an extensive data base, my observations of the cut-throat seep communities and personal communications with others who have experimented with prescribed burning of this community (Bacchus 1992) supports the assumption that spring burns appear to be beneficial, possibly even essential to the continued existence of robust, endemic cut-throat seeps. However, this assumption is based on an unaltered hydrology of the wetland. Activities in adjacent uplands may have a pronounced influence on the hydroperiod of associated wetlands. Changes may occur in the levels of both surface and ground water, as well as in the duration the water remains at any given level. If anthropogenic activities result in a reduction in groundwater levels in these and other wetlands, the beneficial aspects of fire can become destructive.

Research has been conducted on the effects of fire on water quantity (Beschta 1990; Cooper 1971) but little attention has been focused on the reverse concern. Various land uses are capable of lowering groundwater levels in adjacent wetlands for sufficient duration to increase damage to soils and vegetation from fires. Two general categories of such land use activities are: 1) surface excavations resulting in drainage; and, 2) subsurface drainage without surface excavations.

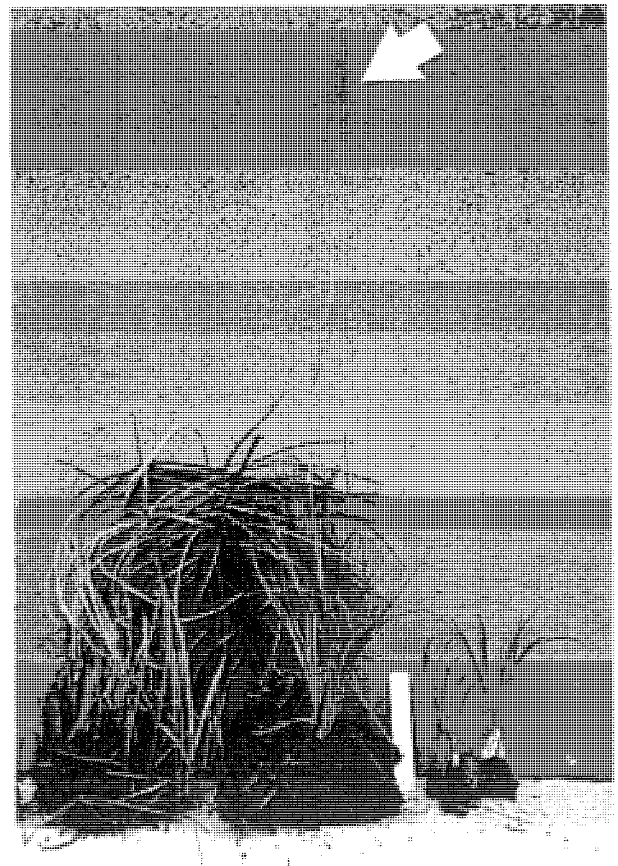

Fig. 4. Variation in growth form and vigor of cut-throat panicum (*Panicum abscissum*) in (left) an unburned cut-throat seep in Arbuckle State Park, south Polk County, FL; (center) an adjacent cut-throat seep of Arbuckle State Forest burned in March 1991; and (right) a nearby cut-throat seep of the Avon Park Air Force Range, north Highlands County, FL, burned in February 1991. The photograph is reproduced with the permission of the Central Florida Regional Planning Council (Bacchus 1992).

Drainage via Surface Excavations

A common misconception is that ditches are the primary means of reducing surface and groundwater levels in wetlands. Drainage of wetlands via surface excavations can result from several types of excavations, with ditches resulting in relatively minor drainage when compared to some other types of surface excavations. Types of surface excavations, listed generally in order of increasing magnitude of drainage potential, are: 1) trenched firelines (as defined by TAC 1993); 2) ditches; 3) stormwater ponds; 4) borrow pits; 5) man-made lakes; and, 6) mining operations. Personal observations, relative degree of subsidence, and simulated cones of influence determined through hydrologic modeling provided the basis for the ranking.

The rate and direction of movement of ground water is controlled by the hydraulic gradient (difference in hydraulic head within and between the substrate), in conjunction with the hydraulic conductivity of the substrate (a measure of the substrate's ability to transmit water, Dennehy *et al.* 1989). Therefore, in reality, ditches excavated in areas with little topographic relief (a common characteristic of the Coastal Plain) and a nonsloping water table may have only a limited influence on the water levels of adjacent wetlands. Conversely, considerable reduction in water levels can occur from seemingly insignificant, shallow firelines and stormwater ponds excavated parallel to the margins of wetlands which receive the majority of their water from lateral seepage of surficial ground water, with periodic sheetflow.

Where seepage wetlands are involved, trenched firelines excavated perpendicular to laterally flowing ground water (parallel to the margin of the wetland) can result in more significant damage to the seepage wetlands through the interception of ground water which would have flowed into the wetland. The magnitude of damage to these systems can exceed damage from ditches constructed through wetlands (parallel to the flow) in areas with little topographic relief in the surrounding uplands and surficial aquifer. Figure 1b is a conceptual portrayal of this phenomenon, with shallow excavations located slightly inward of the two positions of the K_3 symbols. A near-continuous source of incoming water from a slop-

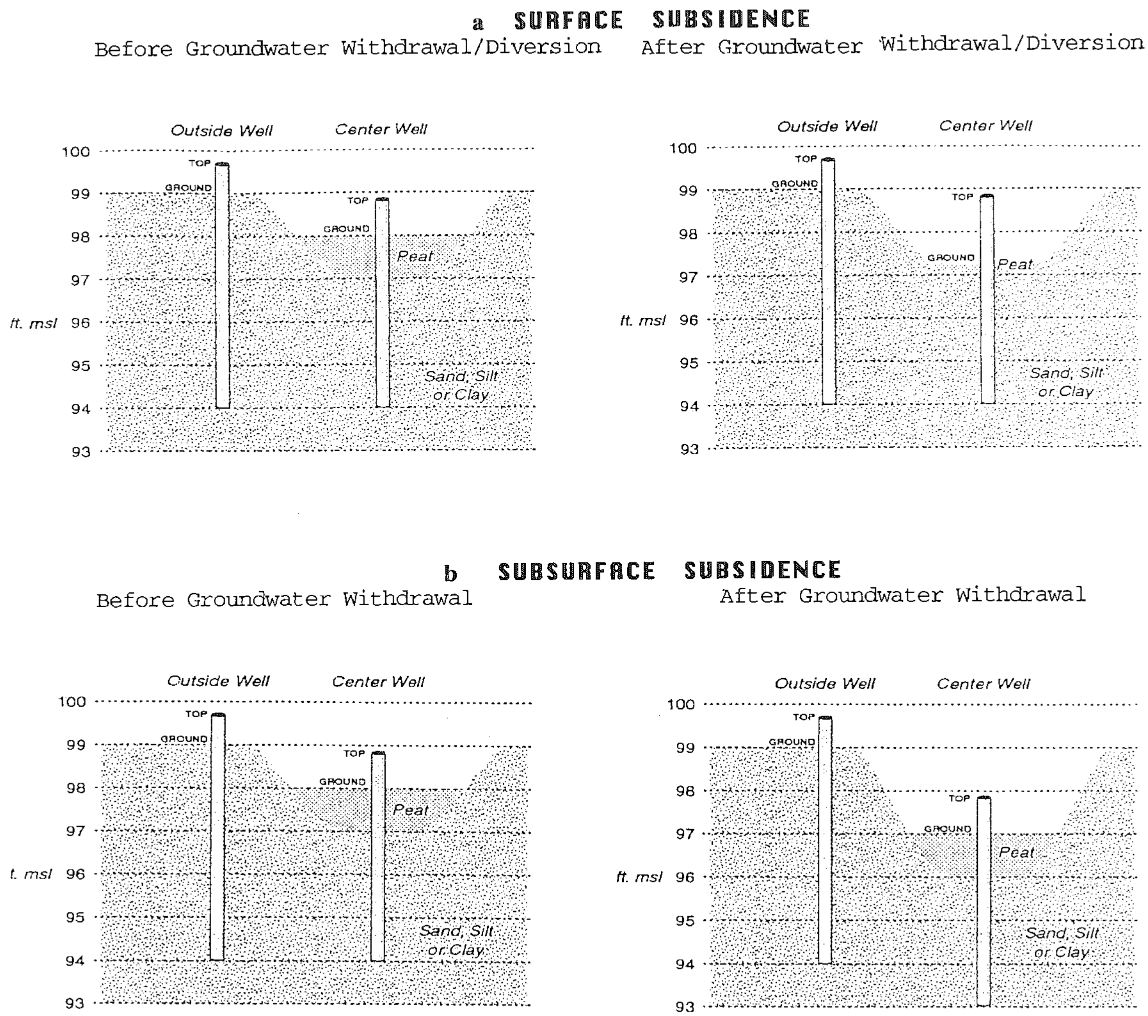

Fig. 5. Two general types of subsidence which may occur in wetlands (center wells), while no change is observed in associated uplands (outside wells), following withdrawal or diversion of ground water: (a) surface subsidence of organic soils which exposes subterranean portions of wells and vegetation, and (b) subsurface subsidence due to structural compaction and collapse (from Rochow and Rhinesmith 1991, text modified).

ing water table now is intercepted. The intercepted water is subjected to higher rates of evaporation following its conversion from ground water to surface water. The increase in water loss through evaporation primarily is a result of increased temperature and exposure to wind. Therefore, even shallow excavations, such as trenched firelines and stormwater ponds, which are excavated perpendicular to the lateral flow of surficial ground water, can intercept sufficient quantities of water to result in reductions of groundwater levels in adjacent wetlands.

When the water table is lowered, moisture levels in the upper layer of soils decline and surface subsidence can occur. Subsidence in organic soils is due to the following factors (Bacchus 1994; Ralston and Hatchell 1971; Zelazny and Carlisle 1974): 1) initial shrinkage following drainage; 2) compaction; 3) oxidation (from microbial processes and fire); and, 4) erosion (from wind and water). Subsidence also can originate below the surface, in the matrix of the confined aquifer, as a result of groundwater withdrawals from the confined aquifer (Bacchus 1994; Rochow and Rhinesmith 1991). This concept will be discussed under the subsection on subsurface drainage.

Figure 5 illustrates the different responses of the surface (ground) to surface and subsurface subsidence (modified from Rochow and Rhinesmith 1991). Plant roots become exposed as a result of subsidence of the organic soils at the surface. Subsequent fires can destroy vegetation which may have survived for years following drawdowns and subsidence, by killing the exposed root systems. Where roots are not exposed, flameless fires that smolder through organic soils can destroy entire wetland communities. The greater the depth of moisture depletion, the greater the amount of organic soil consumed, when present. Under the worst case scenario, these wetlands convert to uplands.

Under Florida's climatic conditions, Stephens (1956, 1969) reported an average rate of loss of 3 cm/yr (1 in/yr) for a thick layer of organic soils due to subsidence associated with ditching of wetlands in south Florida. Examples of similar responses have been observed by the author in shallow wet prairies of the Brumlick tract near the Wekiva River in Lake County, Florida. Losses of five times that amount have been observed by the author in forested seepage wetlands of the Oak Forest development in Seminole County, Florida (Bacchus, unpub. data).

On the Brumlick tract (Seminole Forest), small wet prairies rimmed by shallow (<0.5 m deep) firelines exhibited encroachment of plant species indicative of an altered hydroperiod. Similar wet prairies on the same tract, which had no associated firelines, lacked such indicator species and were being used as nesting sites by Florida sandhill cranes (*Grus canadensis pratensis*). These wet prairies were presumably under the same rainfall regime (see Bacchus 1994 for detailed discussion of the "reference wetland" comparative approach). Dwyer (1990) found that Florida sandhill cranes, a species listed as "threatened" in Florida (FGFWFC 1974), typically nested in water 30 to 40 cm deep and that "development-induced" alterations of hydroperiod were implicated in several nest failures.

In the case of the Oak Forest subdivision (inspected by the author prior to construction and other site disturbance), small stormwater ponds were excavated within the pond pine fringe along a pristine forested headwater stream flowing into the southwest portion of Lake Jesup. The ponds contained water for extended periods after rain events, although designed as "dry-bottom ponds". Subsequently, downslope wetlands exhibited a loss of organic soils of approximately 15 cm (~6 in) due to surface subsidence within the first year following excavation of the stormwater ponds. The remaining organic soils consisted of a powdery dry surface layer. Adjacent downslope wetlands not associated with seepage slope excavations did not exhibit subsidence or other indicators of reduced hydroperiods.

Wetlands in Oak Forest now are more susceptible to wildfire. In the case of the Seminole Forest tract, prescribed burns almost certainly will be part of the management plan for this property, jeopardizing those wet prairies which have artificially reduced hydroperiods. It is ironic that firelines, routinely used to protect wetlands from encroaching fire during prescribed burns, also are capable of altering the natural hydroperiod to the extent that small, vegetatively isolated wetlands become vulnerable to fire damage and encroachment of upland species.

This type of hydroperiod alteration is only significant for smaller wetlands; however, these are the wetlands which provide essential feeding, breeding, or nesting sites for many herpetofauna (Moler and Franz 1987; Sharitz and Gibbons 1982). Furthermore, these small, vegetatively isolated wetlands are significant ecologically because they often support species of animals (e.g., Florida sandhill cranes) or plants (e.g., cut-throat grass and an uncommon St. John's wort, *Hypericum chapmanii*) with very limited distribution and/or declining populations. Alternatives to plowed firelines (e.g., mowing or foam barriers) should be used when conducting prescribed burns in uplands associated with seepage wetlands because of the potential adverse effect on the hydrology of these wetland systems. Wetlands where excavations such as stormwater ponds are present should be treated with extreme caution when formulating prescribed burn plans.

Other oversights with respect to the destruction of wetlands from prescribed burns include the failure of the prescriber to realize that large excavations located up to a mile from a proposed burn site can result in significant reductions in groundwater levels in wetlands at the proposed burn site. Such excavations include borrow pits, mines and so-called man-made lakes (which result from conversion of ground water to surface water following excavation of pits and mines). Excavations of this nature are detectable using aerial imagery, but often are not considered when planning prescribed burns because these excavations are not recognized as capable of lowering groundwater levels.

An example is provided in Figure 6 (modified from David Skipp, Geotrans, Inc., unpub.), which shows the response of the water table in a recharge area in central Florida to excavation of a borrow pit, and subsequent conversion of a 14 ha area of ground water to surface water. The drawdown curve shown in this figure depicts the predicted drop in the water table of approximately 1.5 m in the center of three adjacent wetlands (A, F, and G) during the 3-year excavation period for the pit. This figure also indicates the length of time (13 years) predicted for the stabilization of the water table following completion of the excavation.

It is important to note that the 13-year period represents only the time from initiation of the excavation to stabilization of the water table (i.e., no further increase in water levels due to recovery) and not the re-establishment of original water levels. The new equilibrium level for the water table is predicted to be approximately 45 cm below the former level. Modflow was the hydrologic model used to generate the predictions shown, with conservative assumptions and parameters (McDonald and Harbough 1984). This same model also predicted that the new equilibrium level for the water table would extend for approximately 0.5 km from the pit, with 15 cm drawdowns possible as far as 1.6 km from the pit.

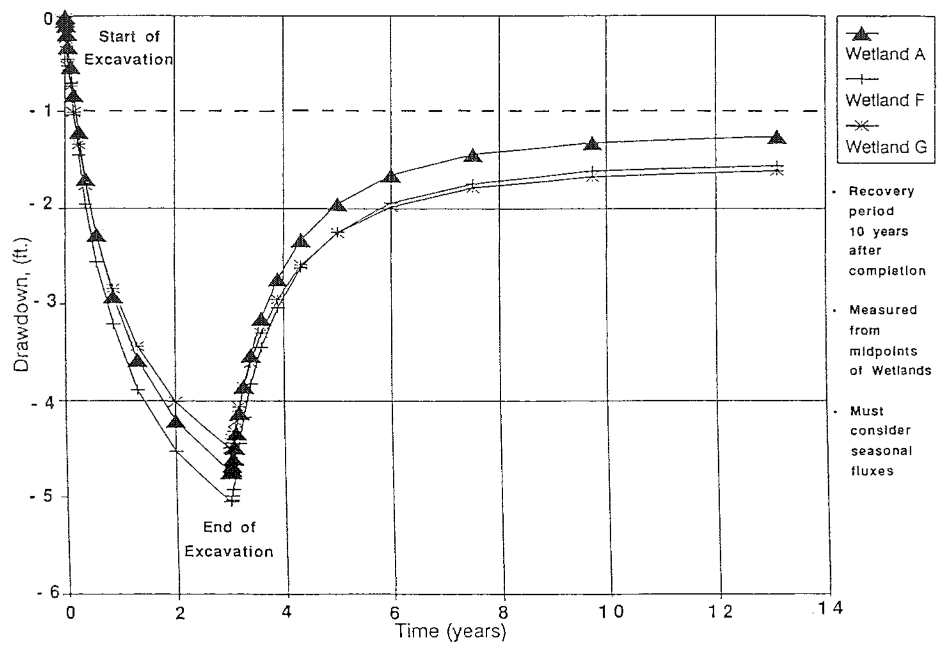

Fig. 6. Predicted Modflow response (transient 3 year withdrawal, TK=1.3e-03) of the surficial aquifer in Geneva, Florida (Seminole County) to excavation of a borrow pit and permanent conversion of ground water to surface water within a 14.2 hectare (35 acre) sandhill (modified from D. Skipp, GeoTrans, Inc., unpublished transcript, Florida Division of Administrative Hearings, C.R.O.P., Inc. vs. James P. Veigle, Inc. (92-0894) 1992).

Even after stabilization of the reduced water table has occurred, moisture levels in the soils within the limits of the root zones of most wetland vegetation will remain lower than normal for a distance of approximately 0.5 to 1.6 km from this excavation. This means that, although the vegetation in these wetlands may not die immediately as a result of the reduction in groundwater levels, the vegetation and hydric soils are more susceptible to destruction by fire.

Similar responses were predicted to occur in The Nature Conservancy's Tiger Creek Nature Preserve, Polk County, Florida, if a proposed Standard Sand and Silica sand mine had been permitted and excavated adjacent to the Preserve. Significant drawdowns from the proposed sand mine also were predicted to occur in Lost Lake, Lake Patrick, Lake Moody and the Blue Jordan Swamp located approximately 5 km away (Curtis 1987).

Permanent reductions in groundwater levels occur primarily as a result of: 1) an extensive increase in the "void space" which the ground water previously occupied, following removal of the soil and resulting pit; 2) an increase in evaporational losses due to conversion of ground water to surface water; and 3) permanently reduced recharge.

Figure 7 illustrates how the water level would respond if a pit (dredge pool) is considered as an enclosed cube of a unit dimension which is filled with a sandy medium having a porosity of 0.20 (i.e., 20% void space). If the initial water level is at the surface of the cube (signified by the inverted triangle in Fig. 7a) and all of the sand is removed from the cube, while retaining all of the water within the cube, the new water level drops to two-tenths of the total volume of the cube (Fig. 7b). In reality, initial reductions may be more dramatic since a portion of the water generally is removed during the mining process.

Although initial declines in the water table due to excavations in similar substrate throughout the coastal plain are this dramatic (Fig. 7), the walls of these excavations generally are unlined, resulting in a direct connection to the surrounding surficial aquifer. As a result, water levels within these pits will rise as water from the surrounding area (including wetlands, lakes, and streams), pours into the pit. The rapid movement of water out of surrounding areas is prompted by the creation of a strong hydraulic gradient following excavation. This gradient is capable of causing local flow reversals for considerable distances throughout the surficial aquifer.

The conversion of approximately 20% pre-excavation void, or pore space, to 100% post-excavation void space in excavated areas is only one reason that the water table reaches equilibrium at a lower level than occurred prior to excavation. A second reason is that evaporation losses from the system increase when previously sheltered ground water is subjected to increased temperatures and wind after becoming surface water. The assumption that evaporative water loss from the pit will exceed water loss from evapotranspiration which resulted from the pre-existing vegetated surface is supported by the following: 1) the water surface is exposed constantly in the former case but may drop below the level available for extraction by roots in the latter; 2) plants can employ mechanisms that restrict water loss, while exposed water surfaces cannot; 3) plants have diurnal and seasonal periods of quiescence when water loss is negligible, while exposed water surfaces do not. Finally, "excavation of sand would decrease the water storage ability of the area and the recharge rates to the wetlands" (Curtis 1987), resulting in permanently lowered water levels in the future from reduced recharge, since "sand mining will alter the recharge in perpetuity" (Curtis 1987).

General knowledge of the potential magnitude of response of the surficial aquifer following various types of surface excavations may improve predictions and control of wildfires, as well as the preparation of a successful burn prescription by providing focal points where additional information should be obtained. For example, the frequency, intensity, and extent of damage from wildfires appears to be increasing in Polk County, Florida, based on observations by the District Manager for the Florida Division of Forestry (Mark Hebb, pers. comm.). Although reductions in the water table following excavation activities are immediate, the influence on burn responses may be delayed or may intensify over time. One delayed response can be attributed to an increase in fuel if vegetation in drained wetlands shifts from low fuel species (e.g., pondcypress) to high fuel species (e.g., pines). Such changes have been observed in Polk County (Mark Hebb, pers. comm.).

Damaging fires in both wetland and upland communities in the southern portion of the Tosohatchee State Reserve in Orange County, Florida are associated with areas of borrow pits (Charlie Matthews, Florida Department of Environmental Protection, pers. comm.). The conversion of wetlands to uplands and the death of upland vegetation which generally is tolerant of fire in isolated areas appear to be related to the excavation of these pits rather than to weather or climatic conditions. This conclusion is based on observations of similar plant communities in the Reserve which receive similar rainfall but have not been adversely affected by fires. This observation is valid even for those wetlands associated with sizable ditches.

It is important to note that the various types of surface excavations discussed above ultimately result in diversion or reversal of flow of ground water. However, since the excavations are visible on the surface, these types of drainage activities are more readily detectable to a resource manager when preparing fire prescriptions than when drainage occurs without associated surface excavations, as discussed below.

a

b

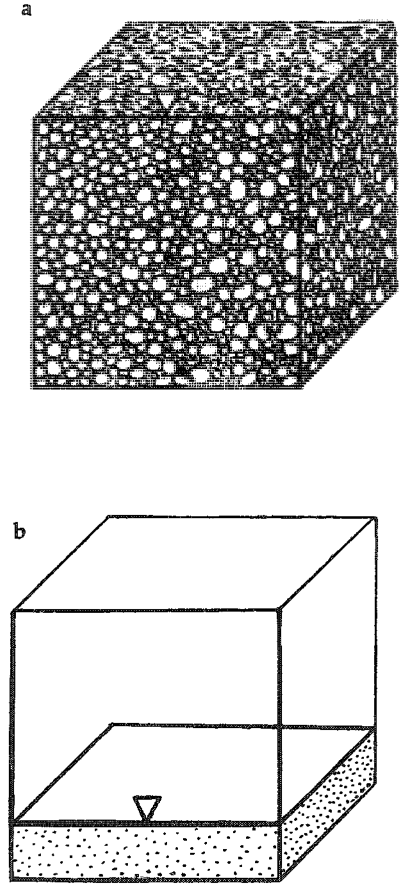

Fig. 7. Increase in total void space and subsequent decline in water level following removal of sand with a porosity of 0.20 from a cubic container of unit dimension, with (a) an initial water level at the surface, and (b) resulting water level at 20% of the total volume after all solids (sand) have been removed.

Subsurface Drainage without Surface Excavations

As discussed previously, reductions in groundwater levels generally are associated with surface drainage from ditching. However, artificial reductions in groundwater levels also result from subsurface drainage without surface excavations. Subsurface drainage of wetlands results from abnormal increases in vertical or lateral movement of ground water from the surficial aquifer (water table), which maintains the wetlands.

A typical profile of one type of pondcypress wetland, a dome, is shown in Figure 8a. The lower, limestone formation is representative of the Floridan aquifer, which is the primary source of fresh water throughout Florida. This aquifer is overlain by layers of lower permeability material (e.g., marls and clays) which retard the exchange of waters between the deeper Floridan aquifer and the surficial aquifer. The upper limit of the water table, represented by the inverted triangle, extends through the organic and sand layers. The small arrows in Figure 8a represent the natural water budget conditions, including

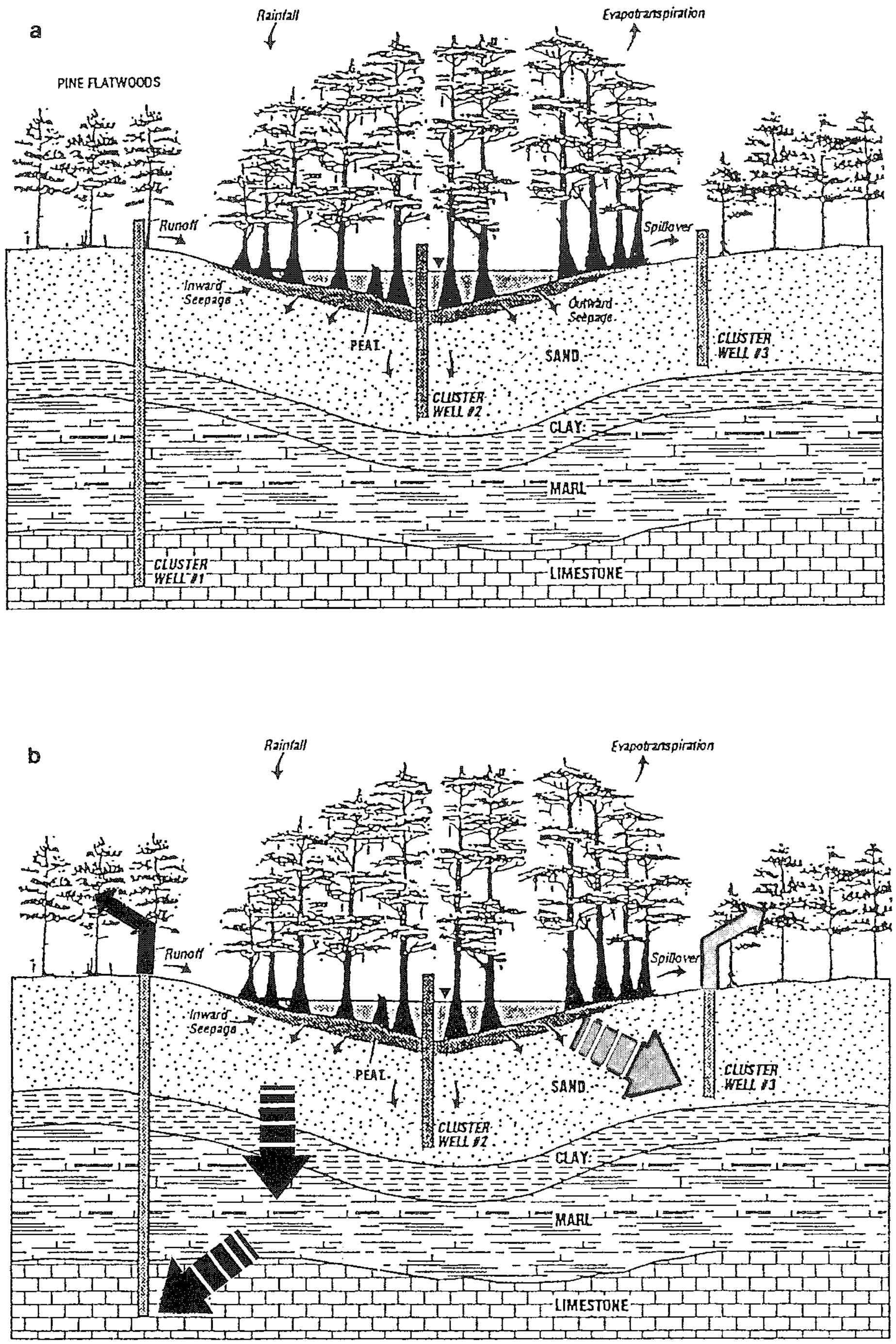

Fig. 8. Typical profile of a cypress dome showing (a) standard water budget inflows and outflows as small arrows (from Watson et al. 1990), and (b) response of the surficial aquifer to shallow and deep aquifer pumping as large solid arrows and subsurface irrigation as large shaded arrows (modified from Watson et al. 1990).

standard inflows (e.g., rainfall, runoff, and inward seepage) and outflows (e.g., evapotranspiration and outward seepage).

Under natural conditions, water levels fluctuate in such a manner that standing water occurs in these wetlands during portions of the year (inverted triangles in Fig. 8). However, the peat or organic layer resting on top of the sands retains sufficient moisture during periods of low-water, even during times of drought, in wetlands with undisturbed hydrology. It is this moisture that keeps the organic soils and plant roots from being consumed by fire in this wetland. The photographs in Figure 9 illustrate this concept. Pond cypress in a wetland with no apparent anthropogenic hydroperiod alteration (Fig. 9a) were unaffected by a prescribed burn (note charred bark approximately 2 m high). Typical wet prairie ground cover, with maidencane (*Panicum hem-*

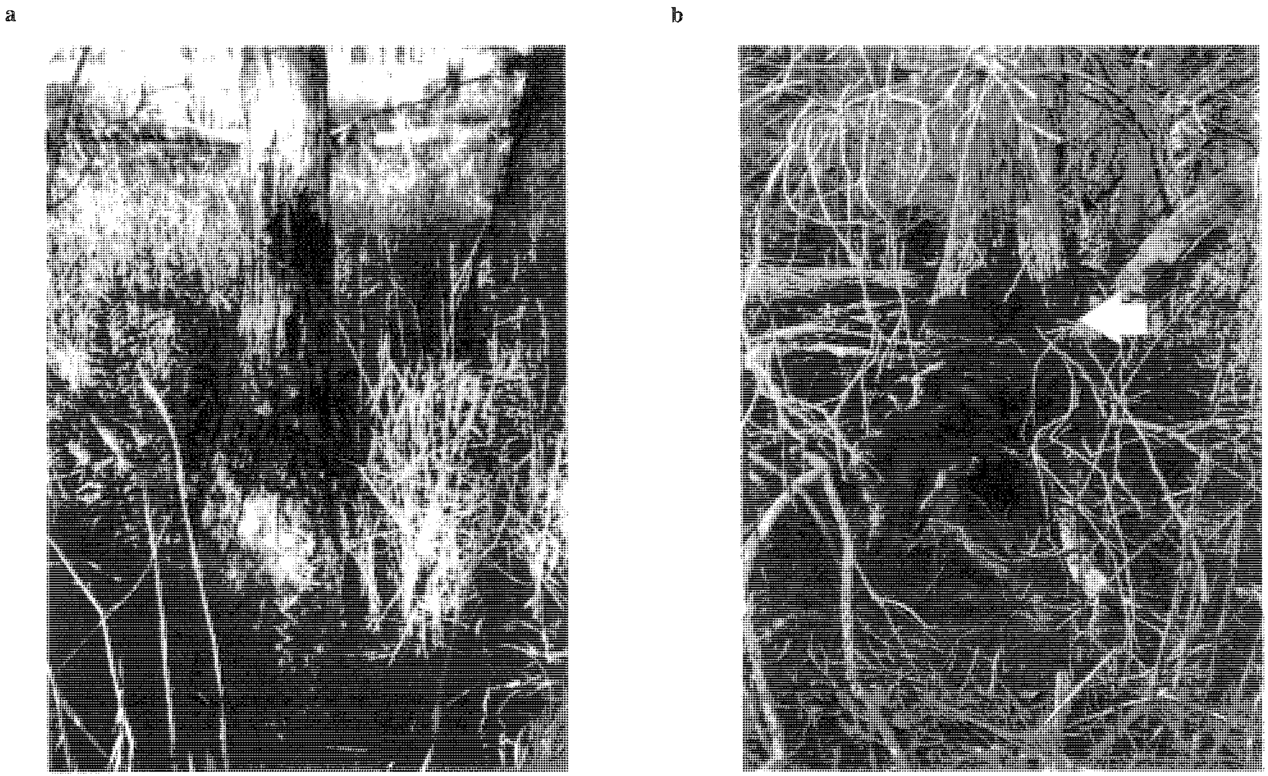

Fig. 9. Following burns (a) no damage occurred to trees or organic soils in a wetland which did not appear to be associated with anthropogenic alteration of groundwater levels and (b) trees were killed and organic soils were consumed in a wetland located adjacent to a municipal well field.

itomon), returned after the fire. Trees in a similar wetland near a municipal well field in Volusia County, Florida, were killed or severely damaged during a prescribed burn (Fig. 9b). The post-fire ground level is approximately 1 m (3.28 ft) lower than the original ground level, indicated by the arrow. Upland species are recolonizing the exposed soil at this site, despite significantly lower ground elevations.

Subsurface drainage of associated wetlands can occur as a result of active groundwater withdrawals for various activities in associated uplands, without surface excavations. Active groundwater withdrawals involve mechanical pumping of groundwater. However, recent evidence suggests that passive groundwater withdrawals in uplands, which involve neither excavations nor mechanical pumping, also can reduce available groundwater in wetlands. Examples of land uses which involve active groundwater withdrawals include, in a general order of increasing potential for wetland drainage (based on empirical data and observations, relative degree of subsidence, and simulated cones of influence determined through hydrologic modeling): 1) residential wells and golf course irrigation; 2) agricultural irrigation; 3) industrial wells; and, 4) municipal wells.

If the deep well in Figure 8b (left) represents a withdrawal (production) well in the deep aquifer for any of the activities listed above (large arrow exiting top of the deep well), the withdrawals could alter the hydrology and hydroperiod of the associated wetlands as shown in the hydrograph of Figure 8b. This occurs because reduction of the piezometric surface increases the hydraulic gradient between the overlying surficial aquifer and the underlying aquifer (commonly referenced as a "confined" aquifer) sufficiently to initiate or greatly increase the vertical flow of water from the surficial aquifer to the underlying aquifer. As stated by Bush (1978) "This assumes negligible lateral flow toward the well field in the water-table aquifer, which seems reasonable since vertical gradients will be orders of magnitude greater than any lateral gradients due to a possible cone of depression in the water-table aquifer".

This abnormally increased vertical flow of ground water from the water table to an underlying aquifer (e.g., the Floridan) is known as downward leakage (large arrows extending from the surficial, sand aquifer, through the clay and marl, into the limestone in Fig. 8b), and also is referred to as induced recharge (Bush 1978), or induced infiltration (Fetter 1988). As the piezometric surface is lowered during withdrawals from the underlying aquifer, compression of the aquifer occurs, resulting in a second form of subsidence (Siple 1967). Compression of the underlying aquifer and subsequent induced recharge can lead to subsidence of organic soils in the surficial aquifer in the absence of any surface excavations.

Although the concept of a confined (artesian) aquifer system predicates the existence of a comparatively less permeable confining bed or aquitard, in actuality, the semi-confining bed only needs to be relatively less permeable than the aquifer. Siple (1967) states that in nature, no stratum is entirely impermeable. Even fine-grained clay has finite permeabilities and hence will transmit finite quantities of water wherever head differentials exist. He concludes that "all confining beds in artesian systems are 'leaky' to a greater or lesser extent, depending on the character and thickness of the rock materials comprising the confining bed."

The hydrographs shown in Figure 10 were compiled from water level data obtained from the Starkey Well Field in Pasco County, Florida. Data from other well fields showed similar patterns and District staff have observed increased susceptibility of these wetlands to destruction by both wildfires and prescribed burns (Rochow 1994).

The magnitude and extent of subsurface drainage of wetlands attributed to the activities listed above will vary depending on the quantity, duration, and season of the groundwater withdrawals. However, it is not uncommon for the adverse impacts of these land uses to extend for considerable distances, draining the wetlands within the cone of influence. For example, Figure 11 shows the contours for the predicted watertable drawdowns centered around the Cypress Creek municipal well field in Pasco County, Florida. Drawdowns of approximately 15 cm are shown extending as far as 5 km from the midpoint of the contours. Drawdowns of this magnitude are sufficient to drain the critical upper layer of soil in the wetlands and render both the soils and the vegetation subject to destruction when exposed to fire. Increased destruction of wetlands associated with the Cypress Creek well field also has been reported to occur following wildfires and prescribed burns (Rochow 1994).

Residential and agricultural wells may withdraw water directly from the surficial aquifer, as shown by the large arrows exiting the top of the shallow well on the right in Figure 8. In this case, active subsurface drainage of nearby wetlands would occur from lateral or horizontal movement of ground water out of the wetland (large horizontal arrows) and into the surrounding uplands. Lateral flow responses of this nature have been documented by Riekerk (1993) in areas of Alachua County, Florida. On his research site, the natural flatwoods canopy vegetation had been removed 26 years prior to the study and a slash pine (*Pinus elliottii*) plantation was established surrounding numerous scattered pondcypress domes and sloughs.

The responses documented by Riekerk (1993) included flow reversals (movement of water against apparent topographic gradients) in some cases. This lateral movement of water through the surficial aquifer away from depressional wetlands, in the absence of mechanical pumping, could be the result of replacement of native upland canopy species by commercial slash pine and/or an increase in densities of the same canopy species in close proximity to the wetlands. Either of these two scenarios could result in the following:

1. reduced local recharge from increased interception of rain; and/or,
2. increased local rates of transpiration.

Riekerk (1993) refers to this apparent phenomenon as "subsurface irrigation". Depending on the magnitude of the flow reversals, the effects on the interspersed wetlands may be the same as those which result from mechanical pumping of reduced quantities of ground water. Similar documentation of the influence of single trees of evergreen conifers on local soil water dynamics has been reported by Bouten *et al.* (1992).

Surface alterations such as excavations are detectable through field reconnaissance and readily-available aerial imagery. However, activities resulting in subsurface drainage of wetlands generally are not detectable using these approaches. Therefore, in areas lacking surface excavations, fire managers may not feel the need to conduct thorough on-site investigations, thus missing biotic and abiotic indicators of altered hydrology which would allude to the potential for the destruction of the wetlands under a typical prescribed burn approach.

Such an incident occurred at a State Forest adjacent to a municipal well field in Volusia County, Florida, where a prescribed burn was initiated on December 12, 1991, in a wetland dominated by loblolly bay and pond cypress. Reduced rainfall was eliminated as a primary contributing factor, using the "reference wetland" approach described by Bacchus (1994). Water levels in the natural lake adjacent to the wetlands had been abnormally low for a number of years, reducing moisture levels in the thick organic layer of the wetland. The prescribed fire ignited the organic soil, which burned for days, charring the roots of the trees. Dog fennel (*Eupatorium capillifolium*) and other ruderal, upland vegetation replaced all but the lowest fringe of fire-scarred pond cypress. No natural recruitment of pond cypress was evident by the winter of 1993. The relatively shade-intolerant cypress seedlings are not expected to recolonize the area in the future as the thick groundcover becomes denser. Adjacent upland communities and plant species which normally are adapted to fire management also can become intolerant of fire due to reductions in groundwater levels.

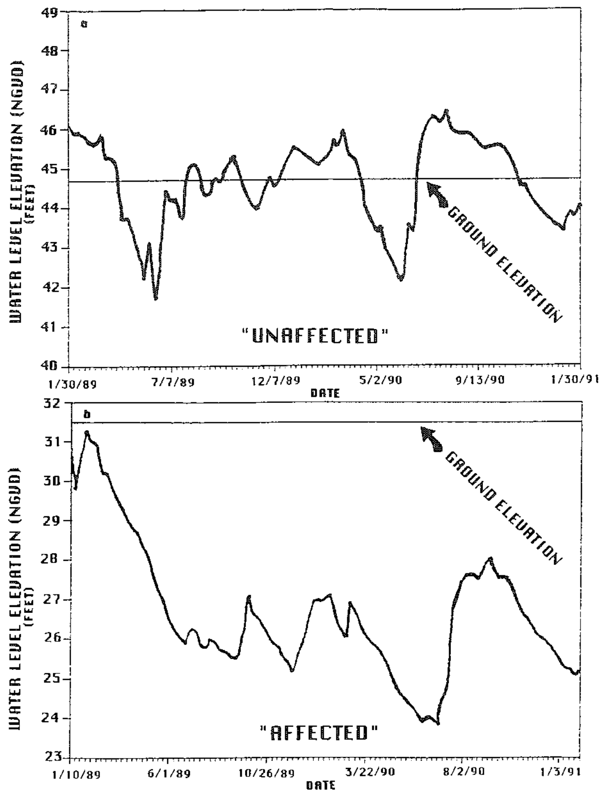

Fig. 10. Hydrographs of (a) "unaffected" and (b) "affected" wetlands at the Starkey well field, Pasco County, Florida (modified from Rochow and Rhinesmith 1991).

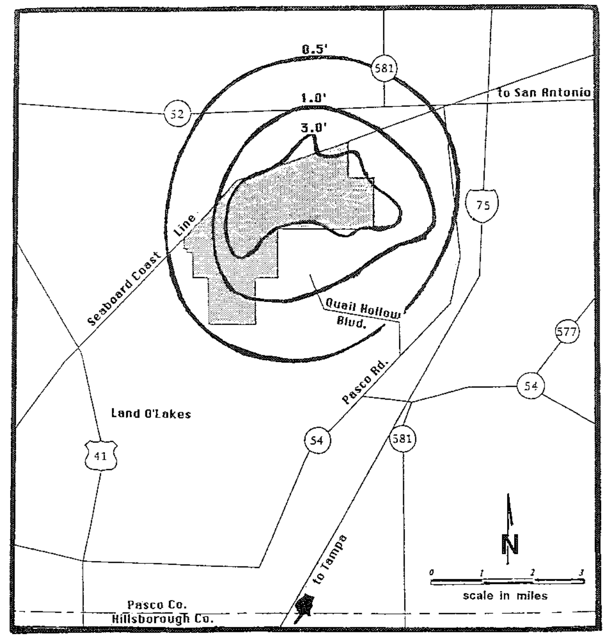

Fig. 11. Predicted water table drawdowns at proposed quantities (30 days at 30 mgd, 60 days at 40 mgd, and 30 days at 30 mgd) after 120 days of pumpage at the Cypress Creek well field (shaded area), Pasco County, Florida (from Rochow 1993).

Shepard (1993) analyzed the areal distribution of hydric soils in the southeastern United States using hydric soil data from the SCS national list of hydric soils. He found that more than 2.8 million hectares of histosols occur in the southeastern United States. Histosols are organic hydric soils which particularly are susceptible to consumption by fire if the water table is lowered and soil moisture levels are reduced.

As noted previously, the Southeast has a greater extent of hydric soils and wetlands than any other region of the conterminous United States. Florida and Louisiana each contain approximately twice the area of hydric soils found in the next highest ranked southeastern states (Shepard 1993). Therefore, extensive losses of hydric soils and wetlands in Florida should be expected to have significance beyond the state and regional level with respect to species such as birds which utilize wetlands during migration, and tourism which is based on natural resources. It is essential that resource managers recognize the deleterious consequences of burning when hydrologic conditions (e.g., groundwater levels) are insufficient to protect associated wetlands from irreparable damage.

Finally, liability associated with prescribed burning is expected to increase dramatically for land managers who ignore the increased susceptibility to fire-related destruction of both wetlands and uplands which are subjected to reductions of groundwater levels. Liability may not be confined to destruction of natural resources as public or private property, but could include destruction of habitat for federally endangered or threatened species, as Hamann and Ankersen (1993) reiterate "Taking is not limited to the physical destruction of a particular individual, but may include taking by 'habitat modification'. . ."

In view of the above, efforts to protect these vulnerable resources from fire-related destruction in areas with reduced groundwater levels should be accelerated. However, this is not to infer that total exclusion of fire is the answer. As discussed previously, some natural communities (e.g., cut-throat seeps, pond cypress wetlands) appear to require or benefit from frequent fire. Development of prescribed burn plans for these communities in areas with anthropogenic alteration of the hydrology will be more difficult.

SUMMARY AND RECOMMENDATIONS

Anthropogenic reductions in groundwater levels have resulted in the consumption by fire of hydric soils which historically were sufficiently hydrated by high water tables to resist surface ignition, as well as the destruction of associated wetlands. The increasing perturbation of groundwater levels through both surface excavations (e.g., trenched firelines, ditches, stormwater ponds, borrow pits, and mined areas) and active and passive subsurface drainage without surface excavations (e.g., subsurface irrigation, and groundwater withdrawals for individual residences and golf courses, agriculture, industry, and municipalities) presents new challenges and increased liability for those who manage Florida's natural resources and commercial silvicultural stands which are planted.

Prescribed burning in the SCP which focuses on weather or climatic conditions without consideration of broader hydrologic components such as groundwater levels which have been lowered by anthropogenic activities will result in increasing losses of valuable hydric soils and wetlands, and in increased liability. Because Florida's hydric soils and wetlands represent a disproportionately large extent of these natural resources as compared to the majority of all other states in the conterminous United States, extensive losses of hydric soils and wetlands in Florida due to fire damage is expected to be of national significance, with respect to the recreational and commercial benefits these ecosystems provide.

Further modifications to the existing meteorological approach of prescribed burning in the SCP, particularly with application in Florida, could minimize the loss of hydric soils and destruction of valuable wetlands. The potential magnitude of the problem regarding loss of hydric soils and wetlands due to fire damage in areas with artificially lowered groundwater levels has been realized only recently. Therefore, the U. S. Forest Service, U. S. Environmental Protection Agency, Florida Division of Forestry, and Florida Department of Environmental Protection should take lead roles, in conjunction with the USDA Soil Conservation Service and the U. S. Geological Survey, in promoting and supporting research directly related to documenting the magnitude and extent of the problem. These agencies then should develop specific hydrologic guidelines which can be incorporated into standard burn plans to protect areas were groundwater levels have been artificially reduced. In the interim, existing prescribed burn courses, brochures, guidelines, policy statements, rules, statutes, training materials and other printed material should be revised to address the problem of damage which can be caused by the current approach to prescribed burning in areas with artificially reduced groundwater levels.

The following recommendations are suggested for immediate implementation:

1. Establish a special category (e.g., "Sensitive Area") to be applied to all locations of large scale water table reductions (e.g., areas of surface mining operations and existing well fields, which can be determined in Florida using Water Management District data), where highly restrictive burning conditions are required.
2. Expand prescribed burn courses and literature to discuss anthropogenic reductions in water table levels and the implications of these reductions to development of fire prescriptions.
3. Require, prior to prescription development, site-specific evaluations by professionals (e.g., Soil Conservation Service Soil Scientists) with training and experience in identifying hydric soils subjected to anthropogenic reductions in water table levels, for less extensive or suspected areas of water table drawdown, as determined by examination of recent aerial photographs and field reconnaissance of wetlands.
4. Apply special category (e.g., "Sensitive Area") criteria to areas identified under 3, above, as areas with artificially reduced water table levels.
5. Initiate a simple inventory process to determine the acreage, location and type (e.g., forested, herbaceous) of wetlands burned subsequent to wildfires or prescribed burns, so that new areas of potentially severe groundwater reductions may be identified.
6. Require alternatives to excavated firelines for small wet prairie systems.

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