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Condition and Change Analysis of Tidal Wetlands on the Squamscott River, Great Bay Estuary, New Hampshire Using Remote Sensing

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Title: Condition and Change Analysis of Tidal Wetlands on the Squamscott River, Great Bay Estuary, New Hampshire Using Remote Sensing

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PROBLEM STATEMENT

Central to all management programs of coastal ecosystems is the ability to recognize whether habitat degradation or losses are occurring. The present report describes the results of a study that utilizes a relatively new technique to assess changes in salt marsh health. The major goals of the study were two-fold: (1) to provide scientists, as well as managers and planners, with an inexpensive technique to assess trends in the health of tidal marshes over the last several decades and to identify potential marsh loss or degradation at very early stages when restoration is simpler and more cost effective; and (2) to initiate research in the Gulf of Maine using this technology. To accomplish these goals, we utilized a marsh condition and change analysis that was based on aircraft photography (generally readily assessable via new overflights and archived photography), desktop computer analysis facilities (PC or Macintosh), and standard software (e.g., Adobe Photoshop).

The marsh condition and change analysis was applied to ten marsh systems along the tidal portion of the Squamscott River in the Great Bay/Piscataqua River Estuary, New Hampshire in order to illustrate and test the methodology, as well as provide much needed research on the level of marsh deterioration or the potential for degradation in the Gulf of Maine. The Squamscott River was chosen for study because of three primary factors: (1) all of the major marsh types found within the Great Bay/Piscataqua River Estuary are represented in this system; (2) the watershed has typical development for this region along its banks (e.g. towns, sewage treatment facilities, farms, bridges and roadways); and (3) this watershed has approximately one fifth of the total area of tidal marshes in the Great Bay/Piscataqua River Estuary (Josselyn and Mathieson 1980, Ward unpublished data).

We define healthy marshes as including dominance of indigenous salt marsh plant species, continuous and vigorous vegetation cover (e.g., limited interior ponds or salt pannes), and stable tidal creek systems. Conversely, increases in open water on the marsh surface represent a step backwards in an evolutionary sense, and signal marsh degradation or submergence. Additionally, the introduction of invasive species such as *Phragmites australis* and *Lythrum salicaria* reflect marsh deterioration due to the ecological losses associated with invasion by these species (Chamber 1977). Also for this study, we define salt pannes as relatively small (usually less than 25 meters in diameter), semi-circular areas on the high marsh surface where standing water is associated with declines in cover and vigor of vegetation. The vegetation that does occur in salt pannes is often different than the surrounding high marsh. In addition, the salinity in the pannes varies widely; standing water can either be very fresh or hypersaline. Interior ponds, which are larger in scale, are irregular in shape and represent topographic lows on high marsh surfaces where water is ponded for extended periods. Similar to the salt pannes, these areas may have residual vegetation, but usually the species assemblages are different than surrounding areas due to the standing water. Vegetative absence is more common in true pannes, quite uncommon in the interior ponds.

Our results show that numerous changes have occurred within the tidal marshes along the Squamscott River during the last 40 years due to both anthropogenic and natural causes. However, where the marshes have not been destroyed or manipulated by humans, degradation was uncommon (not severe when found) with most marsh sites showing reasonable stability. Nevertheless, there are several sites where increases in the extent of interior ponds or salt pannes have occurred in the lower river (i.e., closer to Great Bay). The probable causes of increased salt pannes or interior ponding include: (1) marsh sediment compaction; (2) differential accretion rates on marsh surfaces; (3) ice effects; (4) changes in sediment supply; (5) sea level rise and (6) the accumulation of wrack Although these causes of tidal marsh degradation are only beginning to be understood, potential sites at risk have been identified.

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INTRODUCTION

Overview of the Problem

Tidal marsh loss and degradation along the Gulf of Maine, as well as throughout the United States, are pervasive and serious problems. Tidal marshes are important ecological habitats, that affect the quality of coastal waters. Despite the recognition of such values, tidal marshes are still being lost due to natural (see section on Impact of Sea Level Rise on Tidal Marshes) and anthropogenic effects (see section on Impact of Anthropogenic Effects on Tidal Marshes) at an alarming rate.

New Hampshire, like many coastal states in middle and northern New England, has very limited tidal marshes, with approximately ~25.1 km^2 (6,200 acres) along the Atlantic Ocean coast and the Great Bay Estuarine system (USDA Soil Conservation Service 1994). Because of their limited acreage and high value, it is important that these tidal marshes be maintained and their functional health optimized.

The effects of natural and anthropogenic impacts to northern New England's tidal marshes are fairly clear (Burdick et al. 1997). Nevertheless, systematic identification of deteriorated tidal wetlands in New Hampshire has only been done for hydraulically restricted marshes by the United States Department of Agriculture Natural Resources Conservation Service (USDA Soil Conservation Service 1994). Marshes in early stages of deterioration due to other types of impacts have not been identified, nor has a reasonable method for their identification been developed. Furthermore, the processes leading to marsh degradation are poorly documented (e.g., Sears and Parker 1983, Roman et al 1984, Sinicrope et al. 1990). The lack of documentation is largely a result of the large temporal (long-term) and small spatial scales needed to observe marsh degradation and restoration.

In 1988, the National Wetlands Policy Forum established a goal of no overall net loss of the nation's remaining wetlands. This goal was reaffirmed by the present administration in 1993. In order to provide an ecological basis for management and restoration planning, degrading marshes need to be identified and the processes involved better understood. Such information is critical to the development and implementation of management/restoration plans which would allow salt marshes to maintain themselves as sea level rises. One approach to this problem is to use remote sensing (aerial photography) from various time intervals in order to determine changes, as well as trends in tidal marsh conditions. These changes are then interpreted in a larger framework including sediment supply, sea level rise, and human activities to provide management a context from which they may develop restoration strategies, goals, and assessment criteria to evaluate their programs. The value of tidal marshes, impact of sea level rise, anthropogenic impacts, as well as indicators of marsh degradation are discussed in the following sections to provide the rationale for the approach used in this study.

Value of Salt Marshes

The role of tidal marshes in coastal ecosystems continues to be assessed by the scientific community, but it is clear they serve many important functions. Salt marshes annually produce large amounts of organic matter, which support estuarine communities through detrital food webs. In addition, varying amounts of this material is trapped within the marshes, contributing to the creation and maintenance of the underlying marsh peat (Redfield 1972, Nixon 1982).

Salt marshes improve water quality by acting as filters, removing sediments, nutrients and pollutants from the water column. Waters flooding the marsh surface slows as it passes through the vegetation, causing sediments (Kearny and Ward 1986, Ward et al. in press), as well as nutrients and contaminants bound to or otherwise associated with the sediments to be removed from the water column. Nutrients are taken up by plants to be released as organic forms later in the year. In contrast, most contaminants are slowly buried through the process of sediment accretion (Burdick 1994). Tidal marshes also serve as buffers against storms, absorbing wave energy, detaining flood waters due to baffling effects of plants, and maintaining the elevation of the coastal areas (Knutson et al. 1981, Boumans 1994).

Marshes have long been recognized as critical habitat. Numerous bird and fish species utilize tidal marshes for nesting, breeding and feeding grounds (Short 1992). Because of these functions, many of the values of tidal salt marshes are recognized today and should be a top priority for maintaining the health and quality of the Gulf of Maine (Dionne 1994). Consequently, tidal marsh systems located along New Hampshire's coast need to be managed effectively to maintain and improve the health of our coastal ecosystems.

Impact of Sea Level Rise on Tidal Marshes

Many of the present day tidal wetlands in the Great Bay/Piscataqua River Estuary System were probably formed within the last few thousand years when eustatic sea level rise was slow enough (Belknap et al. 1989) to allow the development of vegetated intertidal wetlands (Trainer 1997). In New Hampshire, the rate of relative or local sea level rise since the 1940's has been estimated to be ~1.5 to 2.0 mm/yr (Hicks et al. 1983), essentially the same rate of the eustatic rise (Gornitz et al. 1982). The relatively slow rate of sea level rise along the New Hampshire coast has reduced the pressure of potential submergence of the tidal marshes. However, other areas of the United States such as Louisiana have experienced substantially higher rates (Stevenson et al. 1986) due to the combined effects of eustatic sea level rise and regional crustal subsidence (due to natural crustal downwarping), as well as anthropogenic effects such as flood control projects and groundwater or petroleum removal. Previous studies in locations where sea level rise has been rapid have provided insights concerning the potential impacts of increasing rates of sea level rise, as well as likely responses to these pressures in New Hampshire. For example, in the Mississippi Delta region and Chesapeake Bay's Eastern Shore (Kearney and Stevenson 1985, Stevenson et al. 1986, Kearney et al. 1988, Reed 1995, Ward et al. in press), sea level rise is exceeding the ability of tidal wetlands to maintain their elevation relative to sea level and marsh losses have become a major coastal problem.

Unfortunately, evidence suggest that the rate of sea level rise will increase during the next several decades due to the greenhouse effect (enhancing the melting of glacial ice and warming of the ocean, Titus and Barth 1984). The New Hampshire tidal marshes that are presently in a dynamic equilibrium with a slow rate of sea level rise may undergo deterioration or loss at higher rates of sea level rise.

Impact of Anthropogenic Effects on Tidal Marshes

Historically, human activities have degraded or destroyed salt marshes throughout the United States. For instance, it is estimated that half the salt marsh acreage that once existed in New Hampshire has been directly destroyed by man (USDA Soil Conservation Service 1994). More recently, stricter coastal development policies have significantly reduced much of the direct anthropogenic impacts (e.g., salt marshes have been protected by Section 404 of the Clean Water Act since 1972). Nevertheless, indirect impacts from coastal construction that limits water exchange and reduces sediment supply often can impact marsh health, diversity and sustainability (Allen et al. 1980, Roman et al. 1984, Short 1984, Zarillo 1985, Dionne et al. 1993, Boumans and Day 1994). For instance, of the remaining 50% of salt marshes that originally existed in New Hampshire, one fifth is currently degraded by indirect impacts due to inadequate tidal exchange (USDA Soil Conservation Service 1994). By restricting flow that carries sediment to the marshes the ability of the marsh to maintain elevations is reduced and the salt marsh begins to degrade (Kearney et al. 1988, Ward et al. in press). Tidal restrictions also reduce biological exchange with adjacent estuarine waters (Herke et al. 1992, Rogers et al. 1992, Burdick and Dionne 1994), decrease salinity levels, cause marsh die-back, cause the replacement of typical salt marsh plants by invasive species like *Phragmites australis* and *Lythrum salicaria* (Sears and Parker 1983, Roman et al. 1984, Short 1984, 1987, Burdick 1992, Burdick and Dionne 1994), or prevent landward migration of marshes with rising sea levels (Pethick 1993, Bird 1993).

In the past, clear cutting of forests for timber or for agricultural reasons has lead to the influx of large amounts of sediment due to erosion and subsequent runoff from the unvegetated land (Trimble 1974). This resulted in the development of tidal marshes in many areas (Meade and Trimble 1974, Ward et al. in press). However, today better farming and timbering practices, along with the damning of the rivers that carried sediment rich water, have resulted in a major reduction in sediment loading to estuaries (Meade 1982). In many areas, this reduction of the inorganic sediment loads has contributed to the loss of tidal wetlands (Stevenson et al. 1988).

Indications of Marsh Loss or Degradation

Increases in the extent of salt pannes and interior ponds as vegetation declines, the presence of invasive species, and the replacement of salt marshes by human development all signal marsh deterioration. The linkage between increased ponding and marsh degradation has been born out by previous work in Chesapeake Bay marshes that have undergone various levels of deterioration or loss (Kearney et al. 1988). Early indications of tidal marsh deterioration in Chesapeake Bay include increases open water (e.g. interior ponds or salt pannes), or increases in tidal channel complexity (Stevenson et al. 1985, Grace 1986, Kearny et al. 1988,Ward et al. in press). Such changes indicate that submergence of the marsh surface and interior pond formation (open water) are related to accretionary deficits (Kearney et al. 1988, Ward et al. in press). Essentially, the vertical accretion rate of the marsh surface has fallen behind the local or relative sea level rise and the marsh surface is unable to build upward at a pace equivalent to sea level rise.

In the sites examined in this report, we define salt pannes as relatively small (usually less than 25 meters in diameter), semi-circular areas on the high marsh surface where standing water has caused significant die back of vegetation. Vegetation witin the salt pannes is often different than surrounding high marsh areas. In addition, the standing water can either be very fresh or hypersaline. During dry periods and neap tides, salt pannes can become hydraulically isolated and can become dry. Interior ponds, which are larger in scale, are irregular in shape and represent topographic lows on high marsh surfaces where water is ponded for long periods. Similar to the salt pannes, they may support risidual vegetation, but usually the species assemblages are different than surrounding areas due to the standing water.

The patterns of marsh degradation observed in New England where tidal flow restrictions have altered marsh function have several commonalties (Burdick 1992, Dionne et al. 1993, Dionne 1994, Boumans and Day 1994, Burdick et al. 1997). For example, barriers to tidal flooding reduce tidal amplitude and flooding frequency on high marshes, reduce salt and sediment exchange, and retain freshwater from rain and spring melt events. All of these aforementioned conditions favor brackish and freshwater plants over salt marsh species. Long-term effects of reduced sediment input associated with restricted tidal exchange include decreasing marsh elevation relative to average sea level and altering flood frequency and duration (Boumans and Day 1994). The end result of the low accretion rate can increase interior ponding on the marsh surface (Kearney et al. 1988, Ward et al. in press). The effects of low sediment supply or rapid sea level rise also can lead to stressful conditions for plant growth (Stevenson et al. 1985, Mendelssohn and Burdick 1988, Mendelssohn and Mckee 1988, Burdick et al. 1989, Dionne et al. 1993), causing die-back and open areas.

With the preceeding considerations in mind, we regard features such as dominance of indigenous salt marsh plant species, continuous and lush vegetation cover (e.g., limited interior ponds or salt pannes), and a stable tidal creek system as signs of good marsh health. Conversely, large amounts or increases in open water on the marsh surface represent a step backwards in an evolutionary sense, and signal marsh degradation or submergence. Additionally, the introduction of invasive species such as *Phragmites australis* and *Lythrum salicaria* reflects marsh deterioration due to the ecological losses associated with plant invasions.

MARSH CONDITION AND CHANGE ANAYSIS

Overview of the Approach

Assessing features that indicate the general health of a marsh system such as presence of salt pannes or interior ponds, plant composition, lushness or vigor of the vegetation, or shape of tidal channels can be readily done on recent, high quality aerial photographs, especially if flown at low water levels using color or color infrared (CIR) film. However, in practice older images are often are of lower quality and many of the characteristics of the marsh system are not distinguishable. Despite this loss in quality, vegetation cover and open water areas often can be discerned with reasonable confidence, especially in computer enhanced images.

Therefore, the analysis of the condition and health of ten marsh systems along the tidal portions of the Squamscott River (Figs. 1 and 2) selected for study relied heavily on the determination of the amount of open water related to interior ponding or salt pannes on aerial photographs. A marsh condition index (MCI) was adapted for this study that categorized the marsh surface largely based on the percent of interior ponds or pannes as indicated by water or lack of vegetation (Table 1); however, other criteria such as the tonal and textural quality of the marsh area was used whenever possible to refine the analysis. The overall characteristics for each MCI value is based on earlier work by Grace (1986), Kearney et al. (1988) and Ward et al. (1988) for identifying marsh condition from aerial photographs of varying quality in Chesapeake Bay, as well as preliminary analysis of sites on the Squamscott River, Adams Point and Rye Harbor, New Hampshire (Ward, unpublished data).

Table 1. Marsh Condition Index or MCI (adapted from Grace 1986 and Kearney et al. 1988).

CLASS*	CONDITION	% OPEN WATER
Class 1	Healthy	0 to 10%
Class 2	Healthy with slight deterioration.	10 to 25%
Class 3	Slight to moderate deterioration.	25 to 50%
Class 4	Moderate to heavy deterioration.	50 to 75%
Class 5	Heavy to complete deterioration.	> 75%

*Complete description of each Class is adapted from Grace (1986)

Class 1: Healthy - marsh has dense stands of indigenous salt marsh vegetation, tidal creeks are sharply defined with nearly vertical banks, tonal characteristics on photographs are even, and less than 10% interior ponding or salt pannes on surface (or greater than 90% of the marsh is vegetated).

Class 2: Slight Deterioration - marsh vegetation dense, but shows some signs of thinning, tonal characteristics on photographs are even, and 10-25% of the marsh has interior ponds or salt pannes (or 75 to 90 % of the marsh is vegetated).

Class 3: Moderate Deterioration - marsh surface has 25 to 50% salt pannes or interior ponds (or vegetation cover is 50 to 75%), tidal creeks are enlarged, vegetation is uneven, and tonal patterns on photographs showing mottling.

Class 4: Heavy Deterioration - marsh surface has 50 to 75% salt pannes or interior ponds (or vegetation covers is 25 to 50%), creeks are enlarged, original channels are difficult to determine, and tonal pattern are extensively mottled.

Class 5: Complete Deterioration - vegetation cover less than 25% or salt pannes and interior ponds cover over 75% of marsh surface.

Application to the Squamscott River

The analyses presented in this report are based upon three types of observations utilizing remote sensing and field verification: (1) qualitative examination of all available aerial photographs of the study area; (2) quantitative analysis of a subset of these aerial photographs accompanied by a marsh surface trend analysis; and (3) field work where vegetation and marsh conditions were assessed. The qualitative examination focused on 1:12,000 color infrared (CIR) transparencies and associated prints obtained during overflights of very low tides in October, 1990, September 1995, and June 1996, as well as various black and white photographs taken from the early 1940s to 1973. Morphological and biologic features such as marsh fragmentation, extent of interior ponding and salt pannes, and presence of invasive plant species were examined to assess the present health of the marshes, as well as changes with time. The quantitative analysis of the photographs focused on the 1954 and 1995 photographs. These dates where chosen because the photographs provided complete coverage of the study sites and were separated by a reasonable time period.

In general, the more recent (1990 - 1996) photographs (CIRs) of the Squamscott River clearly showed features such as vegetation cover or ponded water when present, although the depths of these interior ponds were hard to judge. In older photographs where the quality of the photographs were more variable, and often marginal (e.g., the pre-1970s photographs), it was more difficult to identify vegetated versus unvegetated or open water areas. Care was taken not to mistake tonal or textural differences of the images as flooding of the marsh surface. Also, since the tidal stage of the earlier photographs could only be judged by exposure of intertidal areas, care was taken not to mistake simple flooding of the marsh surface due to recent high tides or rains with more permanent ponding. For the analyses presented here, any questionable areas were not mapped as open water, but left as unknowns or as healthy marsh.

The 1995 and 1996 CIR photographs were taken for this study by the James W. Sewall Company of Old Town, Maine. The 1990 photographs were taken by the same company for an earlier study of tidal marshes in New Hampshire (Ward et al. 1993). These images were available for this study from archives at the University of New Hampshire Jackson Estuarine Laboratory (UNH JEL). 1:12,000 black and white infrared photographs taken in 1973 were obtained from the James W. Sewall Company as well. Older photographs (pre-1970s) were obtained from the United States National Archives in College Park, Maryland.

Analysis of the photographs and trends was based on the previously explained criteria (see Table 1), however, the experience of the investigators in this region was also relied upon. The wetland scientists involved with this project have conducted research in and around the Great Bay/Piscataqua River Estuary for several decades (Josselyn and Mathieson 1980, Daly and Mathieson 1981, Hartwick-Witman and Mathieson 1983, Ward et al. 1988, Burdick 1992, Ward 1993, Ward et al. 1993, Ward 1994, Burdick 1994, Burdick and Dionne 1994, Burdick et al. 1994, Trainer 1997, Burdick et al. 1997). This expertise and earlier reports were applied to the analysis and interpretations presented here.

In general, the following approach was used to conduct the marsh condition and change analysis.

1. A set of recent (1995), high quality vertical aerial photographs (e.g. 1:12,000 color infrared transparencies) was obtained (and archived at JEL) in order to serve as a base against which to measure changes in the study sites.

2. Short-term changes (several years) that have occurred in the marshes under study were determined by comparing the recent aerial color infrared photographs of the study sites with similar photographs obtained in 1990.

3. Longer-term changes (decades) were determined by obtaining vertical aerial photographs of the study sites from as early as possible during this century to the most recent from the National Archives in College Park, Maryland. The best possible sequence of photographs of the study sites from the 1940s to present was assembled.

4. For each study site, a subset of these photographs (1954 and 1995) was digitized, scale corrected and overlain using a computer. However, most images had scale distortions due to tilting of the aircraft.

5. A uniform grid was developed for the 1954 and 1995 digital images that divided the study sites into 50 meter by 50 meter sections. The grids were applied to the images so that all sections corresponded. An alpha-numeric code was then established so that the same area of marsh had the same designation (e.g., A1, A2, B1, etc.).

6. Subsequently, the marsh condition index (MCI) was determined for each grid section (Table 1).

7. The long-term trends of individual sections of the marsh were assessed through time on a section by section basis by determining changes in the MCI.

8. The results of the change analysis were synthesized and used to conduct trend analyses. The 1995 MCI value was subtracted from the 1954 MCI value for each grid unit and the difference

displayed on a map of the marsh system being analyzed. After all of the sections were analyzed and plotted in map form, spatial trends became apparent and areas where marsh degradation or change had occurred became visible.

9. Finally, the present locations of invasive plant species were determined and noted from the most recent vertical aerial photography after ground truth work.

There was some error in the overlaying of the grid, as well as the boundaries of the marsh, as the images were not rectified. However, this did not present a major problem, as the error in overlaying the grids appeared to be less than 5 to 10 meters. Since the grid encompassed a 50 by 50 meter area and the MCI value was an average for the entire grid, the error due to overlaying had little effect. However, the error in overlaying at boundaries did preclude a quantitative assessment of bank erosion or upland encroachment unless it exceeded 10 meters. This type of change was not noted.

All of the computer analysis of the photographs were done on a desktop computer (e.g., Power Macintosh 7500/100) using standard software (e.g., Adobe Photoshop 3.0). The photographs were scanned with a Nikon Touch Scan and saved on Iomega Zip Discs (100 mb) for later manipulations in Photoshop. The maps displaying the results of the trend analysis were made using Aldus Freehand 3.1 on the Macintosh

DESCRIPTION OF THE STUDY AREA

The Squamscott River, which lies in the southwestern portion of Great Bay, New Hampshire, has a drainage area of 331 km^2 (Brown and Arellano 1979), with a calculated mean discharge of 4.4 cubic meters per second (Short 1992). As the Squamscott River is ungauged, the discharge was computed using the size of the drainage basin and the average measured discharge from the Lamprey, Oyster and Salmon Falls Rivers. The Squamscott River extends approximately 11 km from its confluence with Great Bay to the head of tide in Exeter. The channel is shallow with 4.6 meters at mean low water being the deepest channel depth shown on the NOAA nautical chart number 13285. The width of the Squamscott River, along with its tidal marshes, ranges from approximately 1.2 kilometers at the confluence with Great Bay to only approximately 100 meters in the upper reaches. The channel is usually 100 to 200 meters wide. Most of the edges of the river have well developed tidal marshes that are less than 100 meters to approximately 300 meters in width. The marshes that are found in tributary embayments of the Squamscott (Trainer 1997) can be wider, extending over a kilometer inland. The mean tidal range is 2.1 m at the mouth of the Squamscott (NOS Tide Tables 1991). The salinity of the Squamscott River varies a great deal over the year depending on the volume of freshwater discharge (Norall and Mathieson 1976). However, mesohaline conditions typically exist near the mouth of the Squamscott River, while the upper reaches of the Squamscott near the dam in Exeter approach brackish conditions. The local rate of sea level rise for the Great Bay/Piscataqua River Estuary is approximately 1.5 to 2.0 mm/yr based upon tide gauge records from Portsmouth Harbor (Hicks et al. 1983).

Extensive tidal marshes are found along the Squamscott River totaling ~1.89 km^2, which accounts for ~21% of the tidal marsh area in the entire Great Bay/Piscataqua River Estuary system (Josselyn and Mathieson 1980, Ward unpublished data). The tidal marshes are in the "old age" stage of development as described by Frey and Basan (1986), where the amount of high marsh accounts for significantly more than 50% of the total marsh area. Overall, the high marshes in the Squamscott River account for over 70% of the total, Ward unpublished data). However, the marshes in the upper river (south of the Route 101 bridge) would be considered younger from a developmental sense (Frey and Basan 1986), since they are mostly low marshes. In the mesohaline reaches of the lower Squamscott River below the Route 108 bridge nearer the Great Bay, the marshes are characterized by tall *Spartina alterniflora* in the low marsh. The high marshes in the mesohaline region is characterized by *Spartina patens,* with lesser amounts of *Atriplex patulo* var *hastatum, Limonium carolinianum, Salicornia europaea, Scirpus robustus, Solidago sempervirens, Distichlis spicata, Juncus gerardii,* and short *Spartina alterniflora.* Nearer the upland boundary, *Scirpus robustus* and *Typha angustifolia* occur. *Ruppia maritima* (widgeon grass) occurs in some salt pannes. Nearer the middle reaches of the Squamscott River (from Chapmans Landing to the Route 101 bridge), tall Spartina *alterniflora* dominates the low marsh. Some *Amaranthus cannabinus* and *Scirpus robustus* occur along creeks. *Spartina patens*, *Spartina pectinata*, *Soldago sempervirens*, *Scirpus robustus*, *Amaranthus cannabinus,* and *Typha angustifolia* plus lesser amounts of tall *Spartina alterniflora* and *Atriplex patula* are found in the high marshes. An invasive species, *Phragmites australis* is also found near the upland. The upper tidal reaches of the Squamscott River (above the Route 101 bridge to Exeter) where lower salinity conditions are more common has tall *Spartina alterniflora* with some *Amaranthus cannabinus* and *Scirpus validus* in the low marsh, grading into *Typha angustifolia.* The high marsh here is dominated by *Typha angustifolia* with some *Scirpus robustus, Lythrum salicaria* and less commonly extensive stands of *Spartina patens*.

RESULTS OF MARSH CONDITION AND CHANGE ANALSIS

Site 1 - Sandy Point.

General. The Sandy Point marsh system is located on the northeastern side of the Squamscott at the confluence with Great Bay (Fig. 1). The marsh developed over sandy glacial outwash deposits and is relatively thin often being less than 1 meter (Trainer 1997). Vegetation in the low marsh closest to Great Bay and along the small tidal creeks that dissect the marsh is dominated by tall *Spartina alterniflora*. The high marsh is characterized by *Spartina patens, Juncus gerardii* and the short form of *Spartina alterniflora*; with smaller amounts of less dominant species, such as *Scirpus robustus, Limonium carolinianum*, *Salicornia europaea*, and *Distichlis spicata.* Near the upland boundary, *Solidago sempervirens, Atriplex patula, Scirpus pungens, Rhus radicanc*, *Juncus balticus*, *Spartina pectinata* appear, along with stands of *Typha angustifolia* and *Phragmites australis*.

The Sandy Point marsh is now part of the Great Bay National Estuarine Research Reserve and is being managed to promote research and education. A boardwalk has been constructed to allow access to the upland border without disturbing the marsh itself. Several research projects are being conducted in this area. One study is evaluating the recovery of marsh function due to the restoration of tidal exchange in a section of the Sandy Point marsh undrtaken to control the invasive species *Phragmites australis* (Burdick, unpublished data). Furthermore, efforts are underway to measure vertical accretion rates in this marsh utilizing Sediment Elevation Tables (Boumans 1994). The Holocene stratigraphy and recent geological history of this marsh, as well as several others along the Squamscott and in Great Bay, has recently been studied by Trainer 1997.

The 1995 and 1954 photographs (Figs. 3 and 4), as well as ground reconnaissance, indicate the marsh has a very limited drainage system. However, a tidal creek bisecting the central portion of the marsh connects a small pond located on the upland boundary near the railroad tracks to Great Bay. All photographs examined indicate the pond at the head of this tidal creek appears to contain water, excluding the June 1995 image, which suggest much of the pond was dry or covered with floating vegetation.

A second tidal creek towards the eastern boundary of Sandy Point appears constricted in the earlier photographs, but cleaning and enlarging of the channel has re-established its flow. These man-made manipulations were done in order to increase tidal exchange and salinity in order to reduce the expansion of an invasive plant (*Phragmites australis*) that has colonized much of the high marsh at this site. The enlargement of the tidal channel has allowed more tidal water to enter the eastern portion of the marsh on a regular basis, improving drainage and allowing salt water to flood the upland border during spring tides.

Ground reconnaissance of this marsh system in June, 1997 showed a pattern of dead trees along the upland border and on several topographic highs. The trees appear to have died from salt water and marsh encroachment, which may indicate slow tidal flooding of the upland border related to sea level rise. Although widespread upland loss has not occurred, these changes indicate a more gradual transition may be taking place.

<u>Marsh Condition and Change Analysis (1954 to 1995)</u>. MCI analysis of the 1995 images indicates the present marsh is relatively healthy, with little or no signs of degradation in terms of extensive interior ponds. Values of 1 or 2 predominate indicating that less than 25%, and more frequently less than 10%, of the marsh surface is open water (Fig. 5). Nevertheless, there are several areas near the center of the marsh and the upland border that have higher MCI values (3s and 4s), indicating interior ponds and salt pannes are present. In contrast, the 1954 photograph shows more extensive areas with MCI values of 1 and 2 (Fig. 5). Thus, the trend in these areas appears to be increasing amounts of interior ponds. However, the 1954 images are not particularly sharp, causing some ambiguity in the interpretation of the marsh forest boundary and marsh surface conditions. Finally, stands of *Phragmites australis* near the upland border in the 1995 image indicate a form of marsh degradation as *Spartina patens* are displaced by the invasive *Phragmites*.

The marsh surface change analysis that is based upon the change in MCI values from 1954 to 1995 (subtracting the 1995 MCI values from the earlier) shows the increase in the size of interior ponds in greater detail (Fig. 6). Several areas of the marsh appear to be relatively stable over time, as indicated by no change or positive (+1) values (greenish colors on Figure 6), while much of the marsh adjacent to the westward-facing upland border had increased amounts of interior ponds or salt pannes (see reddish colors in Figure 6).

Site 2 - RR East.

General. The marsh system is located on the northeastern side of the Squamscott River just south of the confluence with Great Bay and the railroad causeway/bridge that stretches across the river (Figs. 1, 7 and 8). Site 2 is also located directly south of the Sandy Point marsh system (Site 1) and it was probably continuous prior to the emplacement of the railroad causeway. The estuarine edge of the low marsh is discontinuous with relatively high vertical relief (~1 meter), being dominated by tall *Spartina alterniflora* with some *Atriplex patula*. The high marsh is characterized by *Juncus gerardii, Triglochin maritimum,* short *Spartina alternifora* and *Spartina patens*, with smaller amounts of other species such as *Potentilla anserina*, *Atriplex patula, Limonium carolinianum*, *Salicornia europaea*, *Scirpus robustus.* Near the upland boundary, *Solidago sempervirens* and *Typha angustifolia* were found. Ground inspection of this marsh system in August, 1997 show areas of the high marsh that had been buried by wrack deposits during very high tides that flooded the marsh surface. The wrack had killed the above ground vegetation, perhaps initiating salt panne formation. This process has been observed in several locations on the Great Bay/Piscataqua River Estuary tidal marshes. Areas that are apparently recovering from wrack burial are colonized by *Salicornia europaea*, *Atriplex patula, Scirpus robustus, Spartina alterniflora and Distichlis spicata,* as well as some algae *(Vaucheria spp.* and *Enteromorpha spp.).* Ground inspection in June, 1997 showed that these interior ponds typically had a mixture of plants, including *Distichlis spicata* and *Scirpus robustus* in the center and *Spartina alterniflora* and *Spartina patens* at the edges.

Marsh Condition and Change Analysis (1954 to 1995). Based on the 1995 image, the MCI analysis shows that the marsh system is presently composed of large areas of healthy marsh with MCI values of 1 or 2 (Fig. 9). However, there are also several areas where interior ponds exist and the MCIs values average to 3 to 5. In 1954, tidal flooding of the lower edge of the marsh, as well as the poor quality of the image, hampered the assessment of the condition and change analysis.

The change analysis of the digital images indicate much of the northern half of the marsh has remained stable and that the amount of open water over the entire time period (1954 to 1995) decreased. Frequently, the marsh surface changed from MCIs of 2 or 3 in 1954 to 1 and 2's in the more recent photograph (Figs. 9). These apparently stable areas are shown by the solid green colors in Figure 10. Even so, a relatively large circular interior pond is present in 1995 just south of the railroad trestle, presumably increasing in size since 1954 (see the orange to red colors in Figure 10). Small interior ponds also appear at the head of the northernmost tidal creek in the later photograph, indicating some deterioration and illustrated by the orange sections.

In contrast to relatively large stable marsh areas seen in the northern half of Site 2, the interior ponds in the southern half have apparently undergone significant increases in size (Fig. 10). That is the 1954 image indicates relatively continuous marsh (Fig. 8), while the 1995 image (Fig. 7) shows standing water in several locations. One possibility is that these ponded areas have deepened and contain water more permanently. These areas need to be carefully watched in future years to monitor possible regions of marsh deterioration..

Site 3 - RR Meander

General. The marsh system is located just south of the railroad trestle on the western side of the Squamscott River (Fig. 1). A low marsh area, vegetated with tall *Spartina alterniflora* , is located adjacent to the River and along the large tidal creek that dissects the marsh and forms a tributary (Figs. 11 and 12). The high marsh is characterized by *Spartina patens, Juncus gerardii, Distichlis spicata* and *Triglochin maritimum*; with smaller admixtures of less dominant species such as *Atriplex patula, Limonium carolinianum, Potentilla anserina* and *Solidago sempervirens.* Nearer the upland boundary, *Typha angustifolia, Spartina pectinata, Juncus balticusi, Scirpus pungens, Panicum virgatum, Solidago sempervirens, Carex sp.* and stands of *Phragmites australis* were found. One shrub of *Iva fructescens* was found, notable because this is the northern limit of its distribution. Salt pannes are vegetated with *Spartina alterniflora, Scirpus robustus* and *Distichlis spicata*, with smaller amounts of *Spartina patens* as emergents. *Ruppia maritima* and the green algae *Cladophora sericea* and *Rhizoclonium riparium* occur as submergent.

Marsh Condition and Change Analysis (1954 to 1995). The low marsh at Site 3 in the 1995 image (Fig. 11), appears well developed, with narrow, unvegetated, muddy intertidal banks adjacent to the channel. Although the high marsh shows evidence of increased water coverage due to the large expanse of shallow interior ponds, the low marsh appears vigorous. Geomorphic evidence suggests the low marsh is expanding onto the muddy intertidal flats bordering the channel. The 1954 digital image is not particularly sharp, making interpretation difficult. However, many of the sections where the extensive interior ponds occur on the 1995 image (Fig. 11) appear darker than the adjacent marsh on the 1954 image (Fig. 12), indicating that the ponds existed at the earlier period.

The MCI values for the channelward margin of the low marsh on the 1995 image are dominantly 2s, with some 1s, indicating a healthy marsh with slight or no deterioration (Fig. 13). By contrast, the high marsh in 1995 shows a relatively large amount of salt pannes or interior ponding (Fig. 11 and 13), particularly near the upland border and extending seaward over half the width of the marsh. The interior ponds are a dominant feature for the entire site and extend north of the railroad tracks into the marshes adjacent to the Great Bay. The MCI values assigned to the landward half of the entire marsh system range from 3s to 5s, with 4s and 5s being most common. Based upon the darker color of the marsh near the salt pannes, the 1954 photograph shows a similar pattern. However, there appears to be less open water in 1954 as documented by the slightly lower MCI values assigned to these areas (Fig. 13).

As shown in Figure 14, several significant trends appear to have occurred between 1954 and 1995. Unfortunately, the 1954 image is not sharp causing some ambiguities of the interpretation (Fig. 12). Even so, the portion of the marsh adjacent to the railroad trestle and north of the large tidal channel show increased open water (orange on Figure 12). By contrast, segments of this same area remained stable, or apparently even decreased the amount of open water (green on Figure 12). The MCI for the marsh adjacent to the upper reaches of the tidal channel decreased, indicating the marsh is progressing towards less open water and a more continuous marsh. The area south of the tidal creek on the western bank of the Squamscott River shows a substantial increase in open water from 1954 to 1995 (red and orange on Table 12). Most of this increase occurs south of the tidal channel, in the northern and central portion of this marsh segment. Here the MCIs increased from 2s and 3s to 3s and 4s (Fig. 13).

Site 4 - Chapmans Landing.

General. The marsh system at Chapmans Landing, which is located on the eastern bank of the Squamscott River just north of the Route 108 bridge (Fig, 1), has developed in a former tributary valley that fed into the Squamscott River (Fig. 15). A boat launching facility owned by the New Hampshire Fish and Game agency forms the southern boundary of the marsh. The marsh sediments are somewhat thicker (1.2 to 1.5 meters) than at Sandy Point (Trainer 1997). However, unlike Sandy Point, where the marsh sediments are underlain by sand, a thick sequence of mudflat sediments (up to at least 4.0 meters) are found under the marsh sequence. Channel deposits occur at the base of the tidal flat sediments indicating the ancestral Squamscott River meandered in this area. Even so, Presumpscott Formation sediments are found underlying the tidal flat sequence in some locations. According to Trainer (1997), the ancestral Squamscott probably was eroding into the Presumscott some 12,000 to 8,000 years before present (ybp). Here, the mudflat deposits were not deposited until a couple of thousands of years ago and the salt marsh probably formed in the last thousand years.

A relatively wide low marsh area, vegetated with tall *Spartina alterniflora*, is located adjacent to the main Squamscott River channel. Narrow stands of *Spartina alterniflora* line a very large tidal creek that dissects the marsh. The high marsh is characterized by large areas of *Spartina patens* surrounding low, poorly drained pannes where emergent vegetation (short form *Spartina alterniflora*, plus *Scirpus spp*., and *Salicornia europaea*) is sparse or confined to panne edges. The high marsh is dominated by *Spartina patens,* but include admixtures of other species, such as *Juncus gerardii*, short form of *Spartina alterniflora, Distichlis spicata, Limonium carolinianum, Triglochin maritimum, Salicornia europaea, Solidago sempervirens, Atriplex patula* and *Potentilla anserina.* Near the upland boundary *Spartina patens, Spartina alterniflora* and *Solidago sempervirens* were joined by *Scirpus pungens, Scirpus robustus, Scirpus maritimus, Aster tenufolius* and large stands of *Typha angustifolia*, plus minor stands of *Phragmites australis*.

Numerous large deposits of wrack (accumulations of decaying plant debris) occur near the upland border of the marsh, as well as at a number of scattered locations across the marsh surface. Wrack accumulates and is moved onto the marsh by strong winds during very high tides. Wrack deposits can be large enough and remain long enough to kill the underlying vegetation. The formation of salt pannes and the resulting mosaic of emergent plants on the high marsh is likely impacted by wrack accumulations..

Marsh Condition and Change Analysis (1954 to 1995). The 1995 image shows that the channel margin marsh at Chapmans Landing is composed of healthy low marsh backed by a low, broad levee occupied by high marsh (Fig. 15). However, just landward of this levee, the characteristics of the vegetation change, as does the marsh surface. Here, the marsh has numerous salt pannes and interior ponds that collectively cover large semi-circular areas. The two areas are located on either side of a large tidal creek (Jewell Hill Brook) that traverses the entire marsh system. Outside of these interior ponds, *Spartina patens* dominates the high marsh and levee locations, changing back to *Spartina alterniflora* at the low marsh adjacent to the channels and the interior ponds, where water depths of a few centimeters normally occur. Although unable to be field verified, examination of the earlier photograph indicates these areas were somewhat smaller in 1954 (Fig. 16). Finally, the 1995 image and the 1997 ground truth work shows that the upland border adjacent to the boat landing has stands of *Phragmites australis*, which have displaced salt marsh vegetation, another indicator that deteriorating marsh habitat conditions are present.

The quantitative analysis of the 1995 CIR image indicates the marsh areas exclusive of the interior ponds are very healthy, with little open water rating MCI values typically being 1s, with an occasional 2 (Fig. 17). In contrast, the large salt panne areas have rankings of mostly 4s, and occasionally 3s, indicating poor vegetational conditions and significant standing water. The 1954 image shows less open water, therefore having lower MCIs (Fig. 17) and indicating healthier conditions for emergent vegetation. The trends in MCI values found at Chapmans Landing suggest the low marsh and levee areas have maintained excellent integrity, while interior portions of the high marsh that are poorly drained have deteriorated over the past four decades (orange and red in Figure 18). Large wrack deposits along the upland border have been observed in the 1995 and 1996 photographs as well as during field studies. Vegetation in the areas covered by the wrack will be killed and subsequently may be colonized by different species, depending upon the plant’s opportunity and ability to colonize these patches.

Site 5 - Stuart Farm.

General. The marsh system at Stuart Farm developed in the minor river valley of Mill Brook, a tributary to the Squamscott River (Fig. 19). Originally, the marsh was continuous from the Squamscott River to the upland extent of the V-shaped embayment. A relatively large stream, Mill Brook, entered the back of this embayment and continued on through the marsh as a tidal channel. The access road to the dairy farm was upgraded in 1969 and a bridge over the Brook was replaced by a culvert with a flap gate that excluded tidal flow into the upper half of the marsh. This converted the upper marsh into a freshwater meadow (Fig. 19). By 1993, the meadow immediately upstream of the dike was dominated by *Lythrum salicaria*, and farther upstream, large stands of *Typha angustifolia* and *Phragmites australis* were present. In addition to the biological invasion of this marsh by the exotic *Lythrum*, physical problems occurred. Spring runoff flooded the upstream marsh and threatened the stability of the causeway. Furthermore, salt water occasionally topped the causeway and entered the marsh during severe storms. In 1993, reclamation of the salt marsh was initiated after the removal of the flap gate and the installation of a large culvert (~2.1 meters or ~7 feet in diameter) to allow adequate tidal exchange. Soon thereafter, much of the salt intolerant vegtation was killed and bare areas were colonized by the yellow-green algae *Vaucheria spp*., plus other benthic green algae. By 1997, salt marsh species had returned to the marsh, with *Spartina alterniflora* in the low marsh and the high marsh colonized by *Spartina patens, Juncus gerardii, Salicornia europaea, Amaranthus cannabinis*. The areas uncolonized by salt marsh emergents still supports *Vaucheria* algae. Stands of *Typha angustifolia* and *Phragmites australis* remain, but the exotic Lythrum was killed. Downstream of the causeway, a typical riverine marsh dominated by high marsh remains, with a narrow, deep creek bordered by a thin band of *Spartina alterniflora* (generally less than 5 meters wide). The high marsh is dominated by *Spartina patens*, plus mixtures of *Juncus gerardii*, *Triglochin maritimum, Potentilla anserina, Scirpus spp*. and minor stands of *Carex paleaceae* and *Phragmites australis*.

Marsh Condition and Change Analysis (1954 to 1995). The 1995 CIR image of the Stuart Farm indicates that much of the marsh surface above the causeway and newly constructed culvert had extensive open areas, between clumps of emergent vegetation (Fig. 19). Consequently, the MCI values are high, being mostly 4s (Fig. 21). However, this is expected as part of the reclamation process. It will take several years for the new salt marsh vegetation to completely recolonize the area. Recent monitoring of the reclaimed marsh (1997) indicates that the plants are continuing to expand. Below the culvert, the salt marsh appears very healthy and continuous with MCI values ranging from 1 to 2. In 1954, prior to the efforts to convert the tidal marsh above the causeway by installation of the flap gate, the marsh system at Stuart Farms was relatively continuous with minimal interior ponding or extensive salt pannes. MCI values of the 1954 digital image of Stuart Farm are consistently 1s or 2s from the mouth of Mill Creek to the landward extent of the study area.

Change analysis of Stuart Farm must be viewed with an understanding of the effects of the removal of the flap gate and the installation of the large culvert at the causeway that crosses the marsh. The change analysis shows extensive areas of unvegetated flats documenting the vegetation loss (Fig. 22). However, unlike the other study sites discussed in this report, the increase in open water on the upper marsh area is not related to interior pond or salt panne formation. Instead, the increase in MCI values reflects the early impacts of the reclamation efforts that returned tides to the marsh and caused the die off of the fresh meadow plants. Subsequent to the 1995 photographs, this area had been recolonized by salt tolerant plants and little open water or mudflat area remain. The salt marsh channelward of the causeway has shown little change; hence the trend has been largely towards reduced ponding and greater cover by salt marsh vegetation (Fig. 22).

Site 6 - Southern Meander.

General. The marsh system is located in the middle reaches of the Squamscott River, about half way between its confluence with Great Bay and the town of Exeter (Fig. 2). The marsh developed on a meander bend on the west side of the Squamscott. Here the marsh sediments are relatively thick, ranging between 1.5 to 2.6 meters (Trainer 1977). The stratigraphic sequence at this site as described by Trainer consists of marsh deposits overlying weathered glacial marine sediments of the Presumpscott Formation which was deposited approximately 14,000 years ago or mudflat sediments which were probably deposited within the last few thousand years. The Presumpscott was encountered at ~ 1.5 meters below the present marsh level near the upland border. However, the depth to the Presumpscott increased to over 3 meters nearer the channel. Trainer (1977) speculates the mudflat was initiated here about 2,000 years ago and the marsh within the last thousand years.

The marsh system is characterized by extensive high marsh areas that extend from the upland border to the main channel of the Squamscott River. A narrow, continuous strip of low marsh forms the channelward boundary. The low marsh is vegetated by *Spartina alterniflora* at its lower edge and *Scirpus maritimus* at its upper edge (Fig. 23). Although no natural tidal channels are located in this marsh, numerous (> 15) mosquito ditches create a man-made drainage system that provides significant tidal exchange and drainage across the marsh. The man-made channels either have been maintained or kept open due to tidal flushing since at least since 1954 (Fig. 24). The banks of the ditches form low marsh environments and are occupied by *Scirpus robustus*, *Amaranthus cannabinus*, *Potentilla anserina*, *Solidago sempervirens*, as well as *Spartina alterniflora.* Similar to Chapmans Landing (Site 4), small levees or topographic highs are found near the River, forming high marsh areas that separate the interior ponds from the channel of the Squamscott. The high marsh areas are marked by a discrete band of *Juncus gerardii* and *Solidago sempervirens* surrounded by *Spartina patens*. Vegetation in the high marsh is variable due to changes in elevations. Here levees, typical high marsh having little open water, as well as broad areas where the marsh has extensive, shallow interior ponds with vegetation are found (Fig. 28). The topographically higher areas of the high marsh are vegetated by *Spartina patens,* accompanied by *Juncus gerardii*, *Spartina alterniflora*, *Potentilla anserina*, *Triglochin maritimum*, *Distichlis spicata*, and *Solidago sempervirens*. Stands of *Typha angustiflolia* dominated a large portion of the high marsh adjacent to the upland, and one stand of *Phragmites australis* was observed near the center of the marsh. Other plants typical of the upland border of the marsh were more prevalent in the northern, downstream portion of the marsh: *Spartina pectinata, Panicum virgatum, Scirpus americanus, Rhus radicans, Calystegia sepium* and some *Lythrum salicaria*. The interior ponds of the high marsh where standing water exists has *Scirpus robustus* and/or *Scirpus martimus* and either *Eleocharis parvula* or sometimes *Ruppia maritima*. In shallow pannes, a mixture of *Spartina alterniflora, Salicornia europaea, Atriplex patula* are also found.

The mosquito ditches, which were dug to drain the marsh and reduce mosquito breeding habitat, may aid in stabilizing the marsh surface where large interior ponds exist. That is standing water in interior ponds or salt pannes can stress and kill plants. Therefore, the presence of standing water can enhance or accelerate the formation or enlargement of interior ponds or salt pannes. At Site 6 where the mosquito ditches are most concentrated, salt pannes or interior ponds rarely occur. In the two locations where the largest interior ponds occur, the mosquito ditches are absent or fail to provide an open path for hydrologic exchange. Although we do not currently recommend ditch construction as a management strategy to maintain marsh health, we believe they are important factor in maintaining vegetation cover in portions of this marsh.

Marsh Condition and Change Analysis (1954 to 1995). Examination of the 1995 CIR image indicates that the marsh surface is quite variable (Fig. 23). The upland border has fairly uniform areas of healthy marsh with little or no open water as indicated by MCI values of 1 (Fig. 25). The channelward boundary is fringed with healthy continuous marsh that was assigned MCI values of 2. However, the interior areas of this marsh system, where the interior ponds are found, have extensive regions where MCI values vary between 3s and 4s. Interior ponds on the marsh surface cover approximately one third of the total area. These sites have several types of vegetation, but lie within a matrix of *Spartina patens*. The interior ponds are typically vegetated by *Scirpus maritimus* growing above turfs of either *Eleocharis parvula* or *Ruppia maritima*. The standing water indicates that the ponds are topographic lows within the high marsh, and the species composition suggests that the interior pond waters have a low salinity, at least in spring. Although high MCI values were assigned due to these interior ponds, the ponds appear to have been present during 1954 (Figs. 24 and 25) and do not appear to have increased appreciably.

Change analysis indicates that between 1954 and 1995 a similar pattern of salt pannes and interior ponding existed. The marsh surface change analysis for 1954 to 1995 indicates an increase in MCI values near the Squamscott River margin of the marsh (Fig. 26), although the magnitude is only one MCI unit. Despite the relatively extensive areas of interior ponding or salt pannes in this marsh system in 1995, the MCI values remained stable or only increased slightly (1 unit) between 1954 - 1995. Examination of the MCIs for 1954 shows that the surface had large areas near the center of the marsh with significant open water (MCI values of 3s to 4s). Seaward of these submerged areas, the marsh had less open water (MCI values of 1s or 2s). However, by 1995 the seaward portion of the marsh had increased by one unit (more open water), while the upland portion showed a decrease of one or two units (decrease in open water). Because of the extensive cattail stands that occur near the upland border, areas of standing water may exist, but may not have been clearly visible. Thus, it is interesting to note that if the cattail had increased in this marsh over the past 40 years, the MCI could have decreased, even though the actual ponding on the marsh remained unchanged. This would result because of the ability of the cattail to maintain lush shoots in standing water.

Site 7 - Oxbow

General. The marsh system located just north of the Route 101 bridge crossing the Squamscott River (Fig. 2) has developed along the boundaries of a large meander (Fig. 27 and 28). The stratigraphic study of Trainer (1997), which was based upon three cores along a cross-section over the high marsh inside the meander bend loop, indicates that the Holocene sediment column consists of ~1 meter of marsh deposits overlying 0.3 to 1.5 meters of mudflat sediments. Borings taken at the Route 101 bridge show that the tidal flat deposits can be significantly thicker, reaching up to 6 meters. Beneath the mudflat sequence, sandy sediments (probably deposited in a fluvial channel) or the fine-grained glacial marine sediments of the Presumpscott Formation were encountered. The Presumpscott is on the order of 14,000 years old. A carbon-14 date (AMS) of organic material found in the channel fill material gave an age of ~7,600 years, significantly post-dating the Presumspcott sediments (Trainer 1997). Similar to the other locations on the Squamscott River, the mudflat sediments were initiated on the order of 2,000 years ago, while the marsh probably started forming about 1,000 years ago.

The marsh system in this area has been impacted by numerous human activities. The Route 101 bridge, which now forms the southern boundary of the marsh system, has been undergoing construction since 1995. Although not verified during this investigation, geomorphic evidence suggests that the present marsh system formed as the result of the joining of two meander bend marshes that were separated by the main channel of the river. Formerly, the Squamscott River had a tight meander loop created by normal river processes. A cutoff was dug between 1890 to 1910 at the neck of the meander loop probably in order to decrease the length of the channel, forming the oxbow (the old channel which was abandoned). It is likely that a cutoff would have formed naturally at some point due to the inherent instability of a channel with such a tight meander bend. The formation of the oxbow created a quiet water environment where sediment was quickly deposited. Today, the oxbow has nearly filled in, joining the marshes that were separated by the former river channel and leaving a small tidal creek that is unnavigable over its entire reach. However, this channel provides an important hydrologic connection that provides sediments and nutrients to and from the marsh, as well as drains the marsh at low tide.

The marsh system north of the oxbow (Fig. 27) marks a general transition along the Squamscott River from high marshes dominated by *Spartina patens* to those dominated by *Typha angustfolia* (cattail). Tall *Spartina alterniflora* continues to be the only emergent plant in the low marsh fringe near the banks of the main river channel. However, along the smaller tidal creeks that dissect the marsh, *Spartina alterniflora* is joined by *Amaranthus cannabinus, Scirpus robustus, Scirpus martimus, Potentilla anserina*, and *Atriplex patula*. The high marsh is characterized by *Spartina patens* at the northern end and *Typha angustifolia* at the southern end of the marsh. Areas dominated by *Spartina patens* were relatively diverse, with *Triglochin maritimum, Limonium nashii, Potentilla anserina, Scirpus robustus, Scirpus martimus, Panicum virgatum, Scirpus americanus, Juncus gerardii, Spartina alternifora*, *Salicornia europaea,* and *Solidago sempervirens*. In contrast, portions of the marsh dominated by *Typha angustifolia* had very low diversity. Typically these *Typha* stands had an understorey of *Spartina patens* along the edges, but no other species in the larger, central portions.

<u>Marsh Condition and Change Analysis (1954 to 1995).</u> The marsh system is composed of two somewhat different environments from the northern extent of the meander bend to the Route 101 bridge (Fig. 27). The area north of the oxbow is composed of predominantly high marsh that is dissected by numerous mosquito ditches traversing the area perpendicularly. Here, the mosquito ditches form the main drainage system and apparently are functioning well. This area shows little evidence of salt pannes or interior ponds. By contrast, the oxbow forms a significant low marsh area that surrounds a high marsh with two tidal channels extending into the interior. The area is clearly depositional, with no evidence of marsh deterioration. At present, the former

oxbow has filled with sediment to the extent that two narrow, shallow tidal channels are the only evidence of the former main course of the Squamscott. The MCI analysis of the 1995 CIR image in the area of the oxbow indicates the marsh system is in good health and has little sign of deterioration, with most assigned MCI units being either 1s or 2s (Fig. 29). Marsh conditions observed in the 1954 photograph appear similar to those found today over much of the marsh, although low marsh had just begun to fill in the oxbow (Fig. 29).

Examination of the change analyses of the images from 1954 to 1995 shows three significant or major changes in the marsh over the 41 year period. First, there has been decreases in salt pannes or interior ponds in the high marsh. Secondly, slightly greater amounts of open water now occur just landward of the River margin. Finally and perhaps most dramatic, an extensive low marsh has developed in the oxbow (Fig. 30). On balance, this marsh system is considered in good health and shows no signs of deterioration

Site 8 - Sewage Treatment Plant (formerly the Southern Oxbow).

General. The marsh system located just south of the Route 101 bridge (Fig. 2) originally developed along the boundaries of a large meander in the River. However, around 1966, much of the marsh was filled when the waste water treatment facility (WWTF) or publicly owned treatment works (POTW) was built by the city of Exeter (Fig. 31). Due to the construction of the WWTF, approximately 46,000 square meters (4.6 hectare) of marsh were lost.

We were unable to determine the types of vegetation that characterized this particular marsh prior to the WWTF construction (Fig. 32). However, it is reasonable to assume that the vegetation was similar to that found in the adjacent marsh system (Site 7, see previous description). Today, a small fringing marsh surrounds the channelward edge of the WWTF and it is vegetated by tall *Spartina alterniflora,* grading into a mixture of *Typha angustifolia, Scirpus robustus*, and *Scirpus maritimus,* with some *Spartina pectinata* and *Pontentilla anserina* at the upper elevations. Also, at the channelward margin are two relatively large stands of *Phragmites australi,* with a few scattered stands at upper elevations as well. The stands of *Phramites* most likely developed since the building of the WWTF.

Marsh Condition and Change Analysis (1954 to 1995). The standard MCI analysis was not applicable at most of Site 8 for the 1995 CIR image because of the construction of the WWTF. However, the MCI analysis was applied to the fringing marsh that presently surrounds the WWTF and to the image from 1954 (Fig. 33). As shown in the1995 image, the entire high marsh was removed. Fringing marsh areas have become re-established and appear to be fairly stable as indicated by the predominance of yellow at the margins of the WWTF plant (Fig. 34). However, the natural marsh plant community has been invaded by *Phragmites australis* and *Lythrum salicaria*. Examination of the 1954 photograph (Fig. 32) indicates the marsh prior to construction was in relatively good health as indicated by a predominance of MCI values of 1s and 2s (Fig. 33). However, this analysis is hampered by the lower quality of the 1954 image.

Site 9 - Exeter North.

General. This marsh system is located immediately upstream of the WWTF at Site 9 and just north of the city of Exeter near the limit of tidal influence. The marsh has developed on a moderate-size meander in the river (Figs. 2, 35 and 36). The marsh vegetation for this area of the River is more brackish in character since the salinity can be quite low for much of the year. Here the tall form of *Spartina alterniflora* is found in the low marsh that fringes the channelward margin. Below this cordgrass species, the muddy river banks are sparsely vegetated by *Ruppia maritima*. The sinuous creeks that drain the extensive high marsh are bordered by *Spartina alterniflora*, as well as *Typha angustifolia*, *Amaranthus cannabinus*, and *Scirpus martimus.* The larger creeks support *Atriplex patula* var. *Hastatum* and *Vaucheria* spp., and *Enteromorpha prolifera*. In contrast to the marshes downriver, the high marsh is entirely dominated by *Typha angustifolia* (cattail), with only a single stand of *Phragmites australis* joining the cattails. The high marsh at this site had a notable lack of salt pannes. The upper marsh border is more diverse, with *Spartina pectinata*, *Lythrum salicaria* and the ferns *Onoclea sensibilis* and *Thelypteris thelypteroides* among the pervasive *Typha angustifolia*.

Marsh Condition and Change Analysis (1954 to 1995). Very little change in the amount or pattern of plant cover and open water occurred in this marsh over the period of analysis (Fig. 37 and 38). Examination of the 1995 color infrared image shows that at present, this marsh system is healthy, with no indication of areas of increasing open water (Fig. 37). The MCIs are mostly 1s or 2s, indicating little open water and healthy vegetational characteristics. The 1954 image show similar conditions (Fig. 37). Hence, the trend analysis indicates that little or no increase in the amount of salt pannes or interior ponds has occurred during the last four decades (Fig. 38).

Site 10 - Exeter Marsh.

General. The marsh system located in Exeter (Fig. 2) originally developed along the eastern boundary of a large meander in the river. However, around 1966, a large portion of the marsh was lost due to the construction of a combined sewage outflow (CSO) holding pond for the city of Exeter. During the building of the CSO, a large section of the marsh was converted to pond and upland and encompassed by an earthen dike (Figs. 39 and 40).

Currently, the marsh to the north of the dike is bordered at the channel margin and along creeks by *Spartina alterniflora*, with *Typha angustifolia* dominating interior sections of the marsh. Creek banks also supported tall populations of *Sium suave* (water parsnip) and *Amaranthus cannabinus*, while *Vaucheria* spp. and *Enteromorpha. prolifera* occurred on the creek banks. At upper elevations adjacent to the dike, *Spartina pectinata*, *Solidago sempervirens*, and *Lythrum salicaria* were found. At the southern end of the site, the system is characterized by a low marsh vegetated with *Spartina alterniflora*, patches of *S. validus* at middle elevations, and *Typha angustifolia* dominating the high marsh. This area is very patchy and *Scirpus validus* increases in importance as it appears to displace *Typha angustifolia* at lower elevations.

Marsh Condition and Change Analysis - 1954 to 1995. The 1995 image shows most of the marsh area at Site 10 surrounds the CSO (Fig. 39). Although the river edge is irregular, the marsh appears healthy, having MCI values of 2s (Fig. 41). The 1954 image shows the marsh prior to the construction of the CSO as very patchy (Fig. 40). The MCI values varied from 2s to 5s, with many values in the 3 to 5 range (Fig. 42). Sparsely vegetated low marsh environments probably dominated at this period, accounting for the large amount of open water. The northern end of the marsh is more mature as indicated by the lower MCI units that reflect less open water on the marsh surface. The southern end of the marsh had MCI units of 4s and 5s in 1954, primarily due to the dominance of a sparsely vegetated low marsh. In 1995, the marsh at the southern end of the system below the CSO was still characterized by patchy low marsh, but it appeared to expand significantly to the south onto former mudflats. Whatever the cause, the change indicates marsh building process are resulting in marsh growth

SUMMARY AND CONCLUSIONS

The marsh condition and change analysis utilized in this study provides a relatively quick and inexpensive approach to assessing tidal marsh conditions over several decades along the Squamscott River, New Hampshire. The results of this study show that the marsh systems along the Squamscott River have been affected by anthropogenic, as well as non-anthropogenic influences. Examples of direct anthropogenic impacts include marsh loss or changes due to the construction of the waste water treatment plant (WWTP) and the combined sewage outflow (CSO), as well as the Route 101 bridge, in Exeter. Examples of indirect anthropogenic impacts include mosquito ditching and tidal restrictions (Stuart Farm). Non-anthropogenic impacts are related to sea level rise and subsidence, however, the relatively slow rates at present have minimized these problems. Several of these impacts have lead to the introduction of two invasive species; *Phragmites australis* and *Lythrum salicaria.*

Although no major signs of marsh degradation were found in the tidal marshes at this time, long-term increases in the size of interior ponds and salt pannes occurred in several locations in the lower and middle reaches of the Squamscott River. Overall, most of the interior ponds and salt pannes are found in the lower half of the River starting at about Site 6 - Southern Meander (Fig. 1 and 2) and continuing until the confluence with Great Bay. We regard features such as a dominance of indigenous salt marsh plants, continuous and lush vegetation cover (e.g., limited interior ponds or salt pannes), and a stable tidal creek system as signs of good marsh health. Conversely, large amounts or increases in open water on the marsh surface represent a step backwards in a developmental sense and signals marsh degradation or submergence. Additionally, the colonization and expansion of invasive species such as *Phragmites australis* and *Lythrum salicaria* reflect marsh deterioration due to negative impacts on biodiversity.

Salt pannes, relatively small (usually less than 25 meters), semi-circular areas on the high marsh surface where standing water has caused significant die back of vegetation, often contain different vegetation than the surrounding marsh. The standing water forms an abrupt boundary with the surrounding marsh and can either be very fresh or hypersaline. During drier periods, the salt pannes can become totally dry. Interior ponds, which are larger in scale, are irregular in shape and represent topographic lows on the high marsh surface where water is ponded for extended periods. Similar to the salt pannes, these areas may have residual emergent vegetation, but usually the species assemblages are different than surrounding areas due to standing water. Interior ponds are more likely than salt pannes to have emergent and submerged vegetation. Standing water on the marsh can cause severe stress for marsh plants (Mendelsson and Mckee 1989). Therefore, the presence of the standing water can accelerate the formation (enlargement) of interior ponds and salt pannes. Conversely, it appears that enhanced marsh drainage reduces the stress on the vegetation from standing water, enabling revegetation and decreasing the occurrence of pannes or interior ponds.

Although others probably exist, we present four hypotheses for the formation of salt pannes and interior ponds. These include: (1) an accretionary deficit reducing the marshes ability to maintain its elevation with respect to sea level rise and subsequent trapping of tidal waters or rainfall; (2) the marsh surface accreting unevenly, resulting in areas that are topographically low and predisposed to trap tidal or rain water; (3) ice damage creating small holes and larger depressions on the marsh surface; and (4) the deposition of wrack (dead marsh vegetation that has been drifting about the estuary). These four hypotheses for salt panne or interior pond formation operate on three spatial scales The first process influences large reaches of an estuarine tributary, the second operates within a single marsh system, and the third and fourth processes influence small to moderate areas a within single marsh.

The first hypothesis implies an accretionary deficit causing the marsh surface to be building vertically at a rate less that sea level rise. The balance between sea level rise and vertical accretion in the marshes is a function of sediment input, plant productivity and compaction of the sediment column. In areas where an accretionary deficit occurs, topographic lows can exist, resulting in standing water on the marsh surface. Flooding can result from either tidal action or precipitation. The net result is a decrease in elevation of the marsh surface relative to present local sea level, with the marsh surface becoming submerged. Our research of the marshes in the Squamscott River shows that in some areas these interior ponds are forming.

Related to the first hypothesis is the manner in which marshes undergo compaction and the implications of this to the location and processes of formation of salt pannes and interior ponds. Although we have not documented the process, it is reasonable to assume that thicker and more organic rich marsh sequences will be more susceptible to decomposition and dewatering resulting in more extensive compaction. Since marsh sequences vary in thickness and organic content, different magnitudes of compaction can occur, resulting in topographically low areas on the marsh surface. These areas are sites where salt pannes or interior ponds may form preferentially. Even without sea level rise these topographically low areas can become submerged; however, sea level rise will compound this process. In our investigation of the marshes along the Squamscott River, most salt pannes and interior ponds formed nearer the upland border or in the mid-marsh area where organic contents are the highest.

Although the greater occurrence of the salt pannes and interior ponds in the lower half of the Squamscott River is likely related to several factors, it is reasonable to hypothesize that the inorganic sediment supply plays an important role. For instance, marsh stability is related to higher sedimentation rates in tidal marshes in the upper reaches of an estuarine tributary (Nanticoke River) within Chesapeake Bay (Kearney and Ward 1986). The marshes nearer the headwaters of the Nanticoke were accreting vertically at a pace that maintained their elevation in the face of local sea level rise; however, the tidal marshes in the lower estuary had lower accretion rates. Here, both marsh loss and degradation were occurring (Grace 1986). Kearney and Ward (1986) related the marsh loss and degradation to lower accretion rates, which caused the marshes in the lower Nanaticoke to be susceptible to submergence. Ultimately, this resulted in increased interior ponding of the marsh surface. The greater incidence of salt pannes and interior ponding in the lower Squamscott may be a reflection of lower accretion rates as shown in the Nanticoke River, reducing this regions ability to maintain pace with a local sea level rise of ~1.5 to 2.0 mm/yr (Hicks et al 1983)

The second hypothesis for the formation of the salt pannes and interior ponds is that these topographically low areas within a marsh system have not built upward at the same rate as the rest of the marsh. However, these areas are continuing to build upward and will evolve into high marsh in the future. This hypothesis forces a very different perspective of marsh health in that the system is still evolving to high marsh conditions with some sites lagging behind, indicating that the marsh is in good health and progressing as expected.

The third hypothesis for the formation of salt pannes involves the impact of ice on the tidal marshes. During winter, substantial accumulations of ice usually cover the marsh surface. The above ground vegetation is frozen in the ice and clipped off when the ice becomes moblized by tides or storms. It is not unusual to have blocks of the marsh sediment frozen in the ice as well. If the ice is transported during a high water period by currents or winds, then blocks of the marsh are often “ice rafted” to a new location, either within the same marsh system or elsewhere in the estuary. The net result is that the marsh surface is gouged and a topographically low area devoid of vegetation results. This site subsequently ponds water after ice out and develops a salt panne.

The fourth hypothesis or model for the development of the salt pannes involves the accumulation of extensive wrack deposits during storm surges. Wrack becomes stranded in the marsh when the tidal waters recede and begins to decay. The cover of this material can kill the underlying vegetation. After the wrack decomposes or is removed, the barren area becomes a salt panne or interior pond. Evidence of this process occurring was observed at Site 2 and 4 in June, 1997 during ground surveys.

Continued examination of the marshes through time should indicate which of these models for the formation of salt pannes or interior ponds is more likely. If these interior ponds are forming at present, then the marsh surface trend analysis should indicate that these areas have formed in the recent past or the size of the ponds are increasing. Conversely, if the interior ponded areas are stable or decreasing in frequency or in size, then this would indicate that the sites are now building upward and becoming stable high marsh areas. As these processes of panne and pond formation operate at different spatial and temporal scales and because of the variety of conditions and controlling processes in an estuarine tributary, it is likely all of these modes of development occur.

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Figures 1 through 42

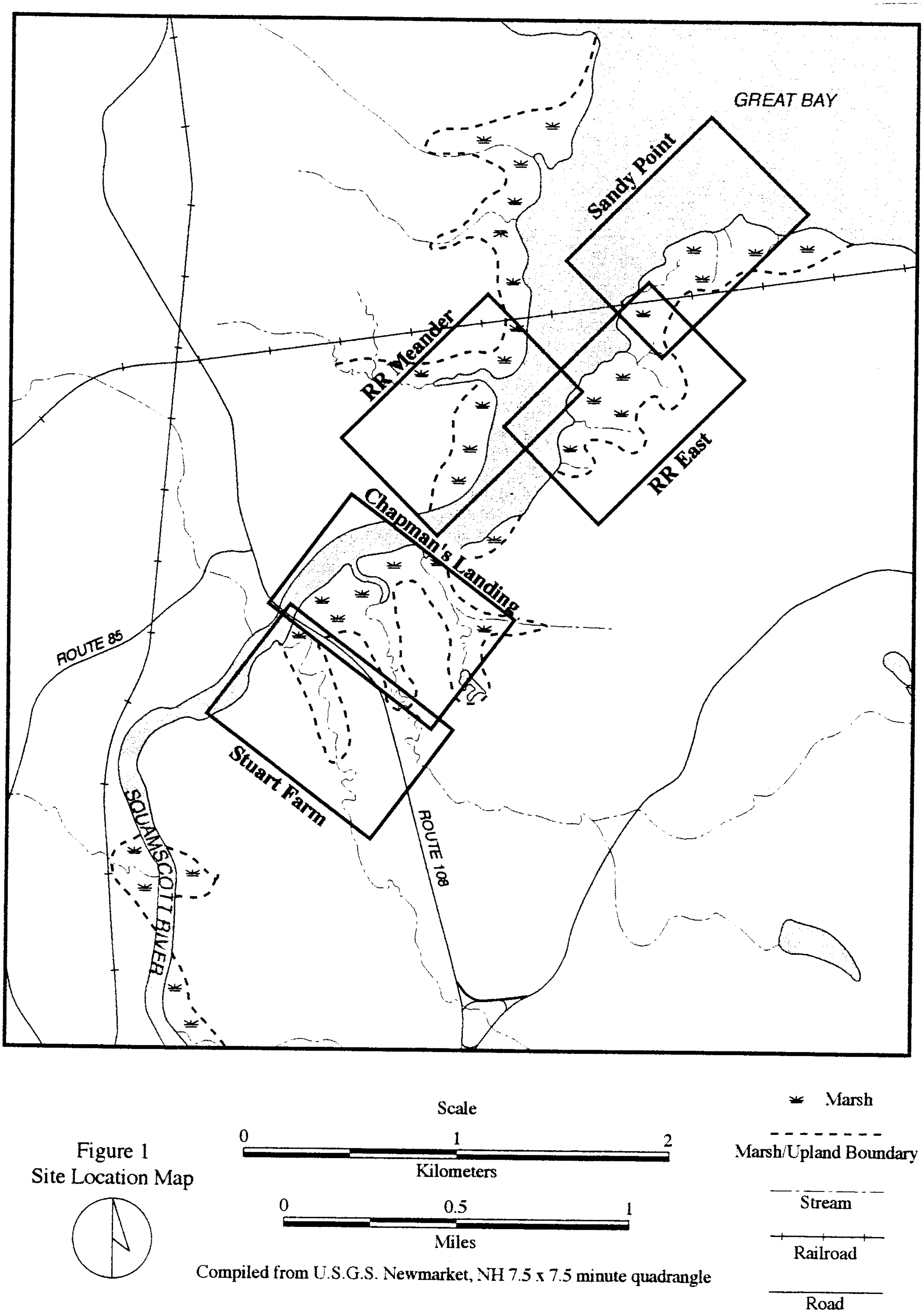


Figure 1
Site Location Map

Compiled from U.S.G.S. Newmarket, NH 7.5 x 7.5 minute quadrangle

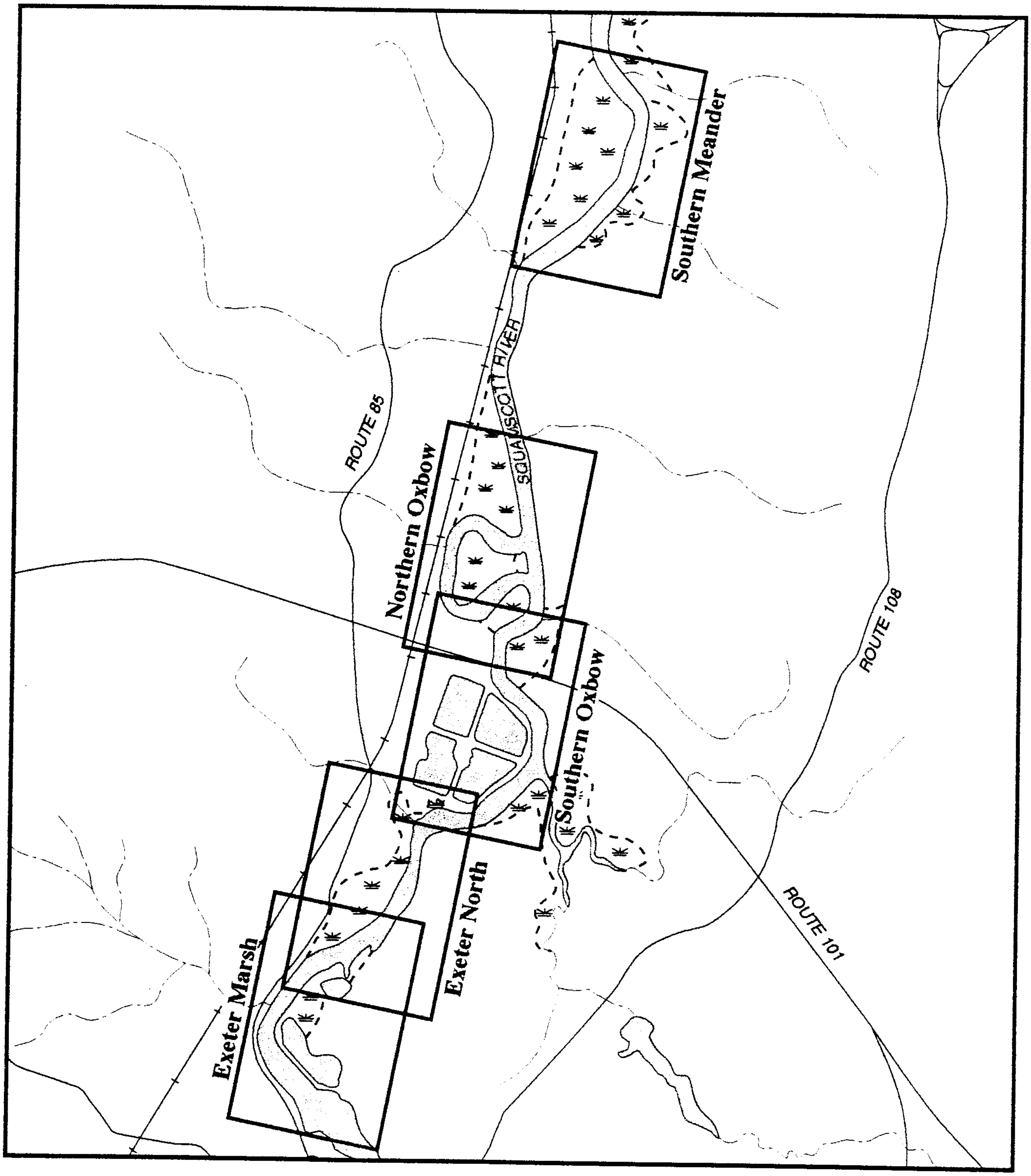


Figure 2
Site Location Map

Compiled from U.S.G.S. Exeter, NH and Newmarket, NH
7.5 x 7.5 minute quadrangles

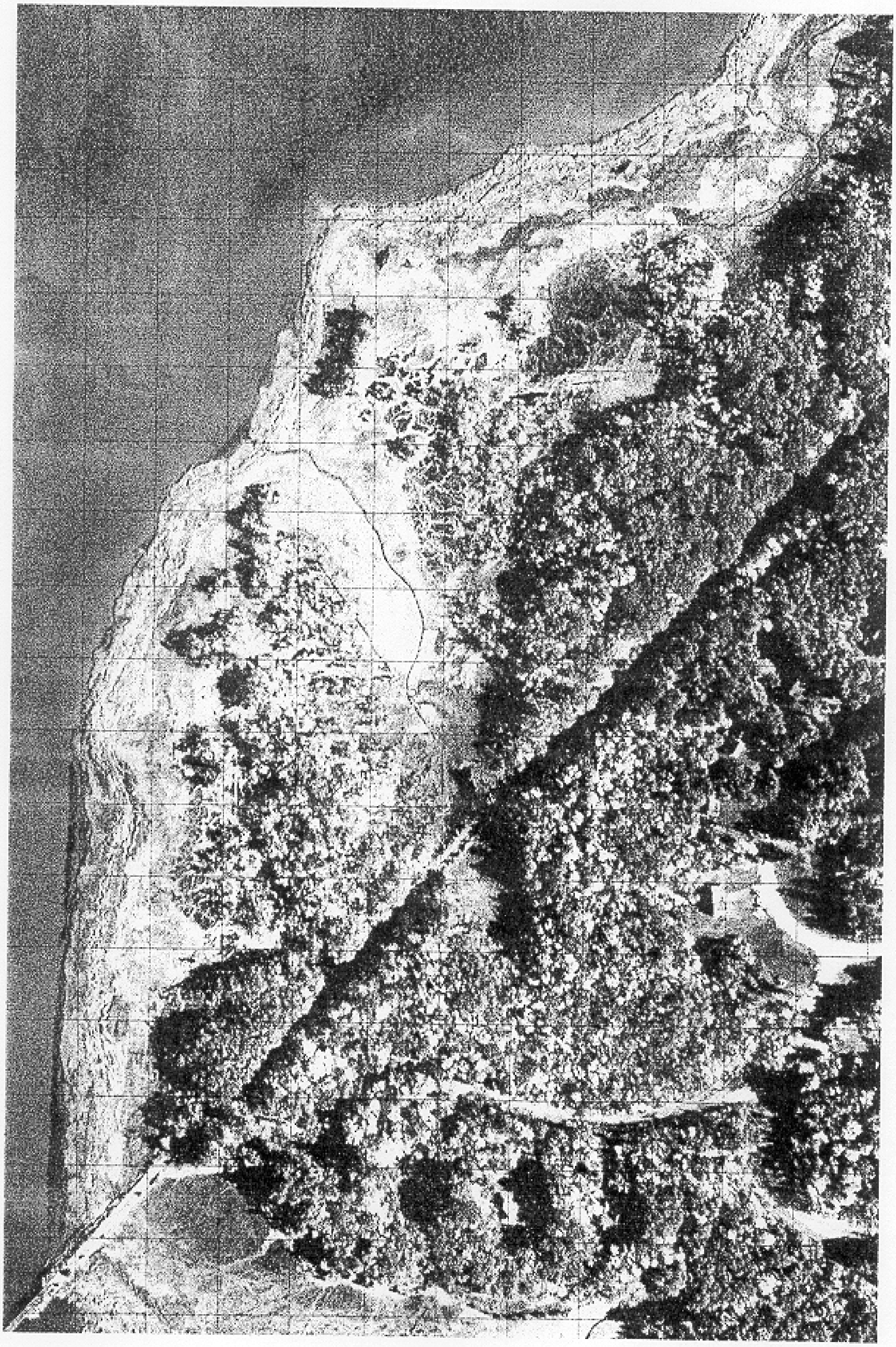
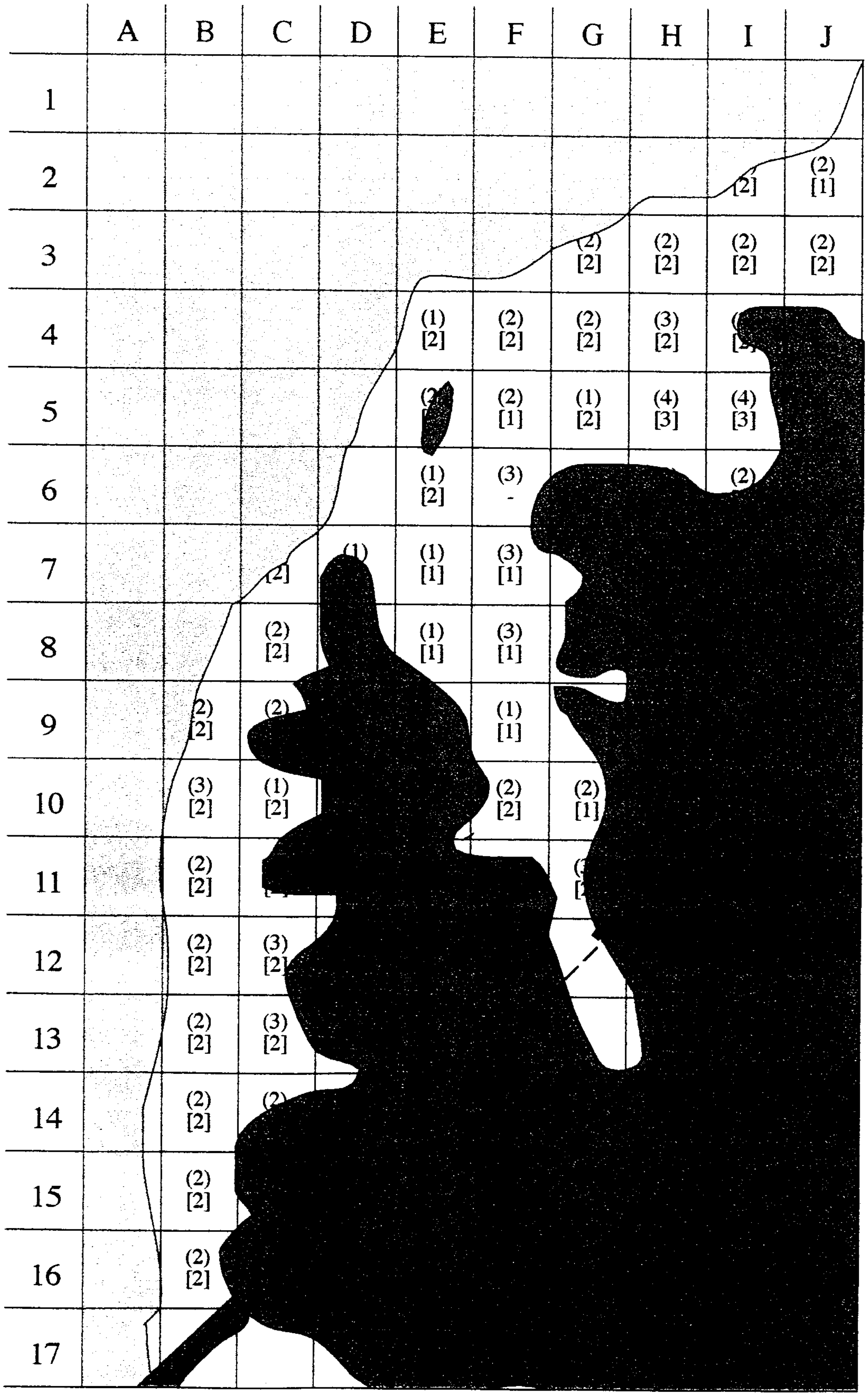


Figure 3. 1995 image of site 1 - Sandy Point.

Figure 4. 1954 image of site 1 - Sandy Point.

Site: Sandy Point 1995/1954 TOP: (1995) BOTTOM: [1954]



	A	B	C	D	E	F	G	H	I	J
1										
2									[2]	(2) [1]
3							(2) [2]	(2) [2]	(2) [2]	(2) [2]
4					(1) [2]	(2) [2]	(2) [2]	(3) [2]	[illegible]	
5					[illegible]	(2) [1]	(1) [2]	(4) [3]	(4) [3]	
6					(1) [2]	(3) -			(2)	
7			[2]	(1)	(1) [1]	(3) [1]				
8			(2) [2]		(1) [1]	(3) [1]				
9		(2) [2]	(2)			(1) [1]				
10		(3) [2]	(1) [2]			(2) [2]	(2) [1]			
11		(2) [2]	[illegible]				[illegible]			
12		(2) [2]	(3) [2]							
13		(2) [2]	(3) [2]							
14		(2) [2]	(2)							
15		(2) [2]								
16		(2) [2]								
17										

Figure 5. MCI analysis of site 1.

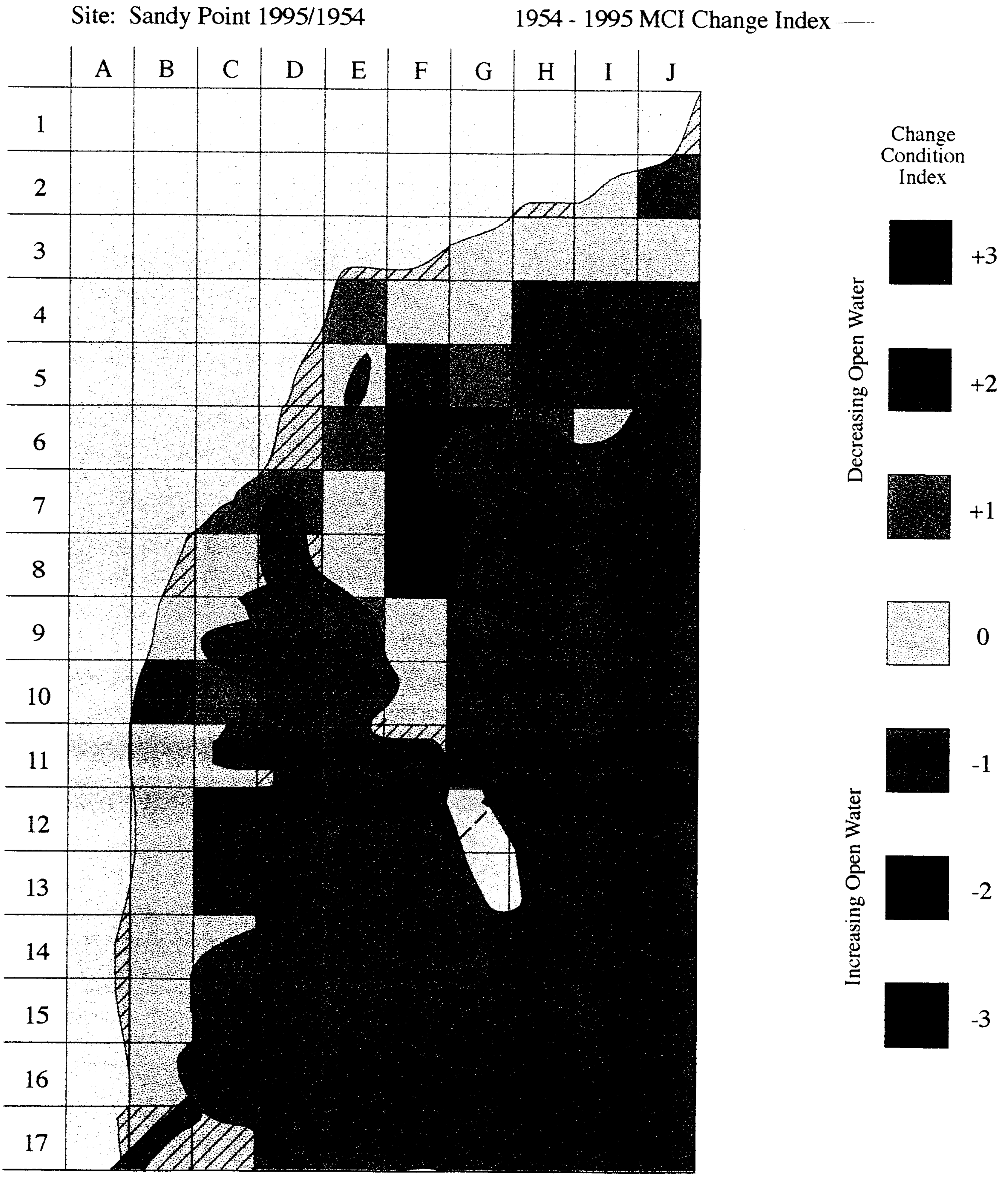


Figure 6. Trend analysis of site 1. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

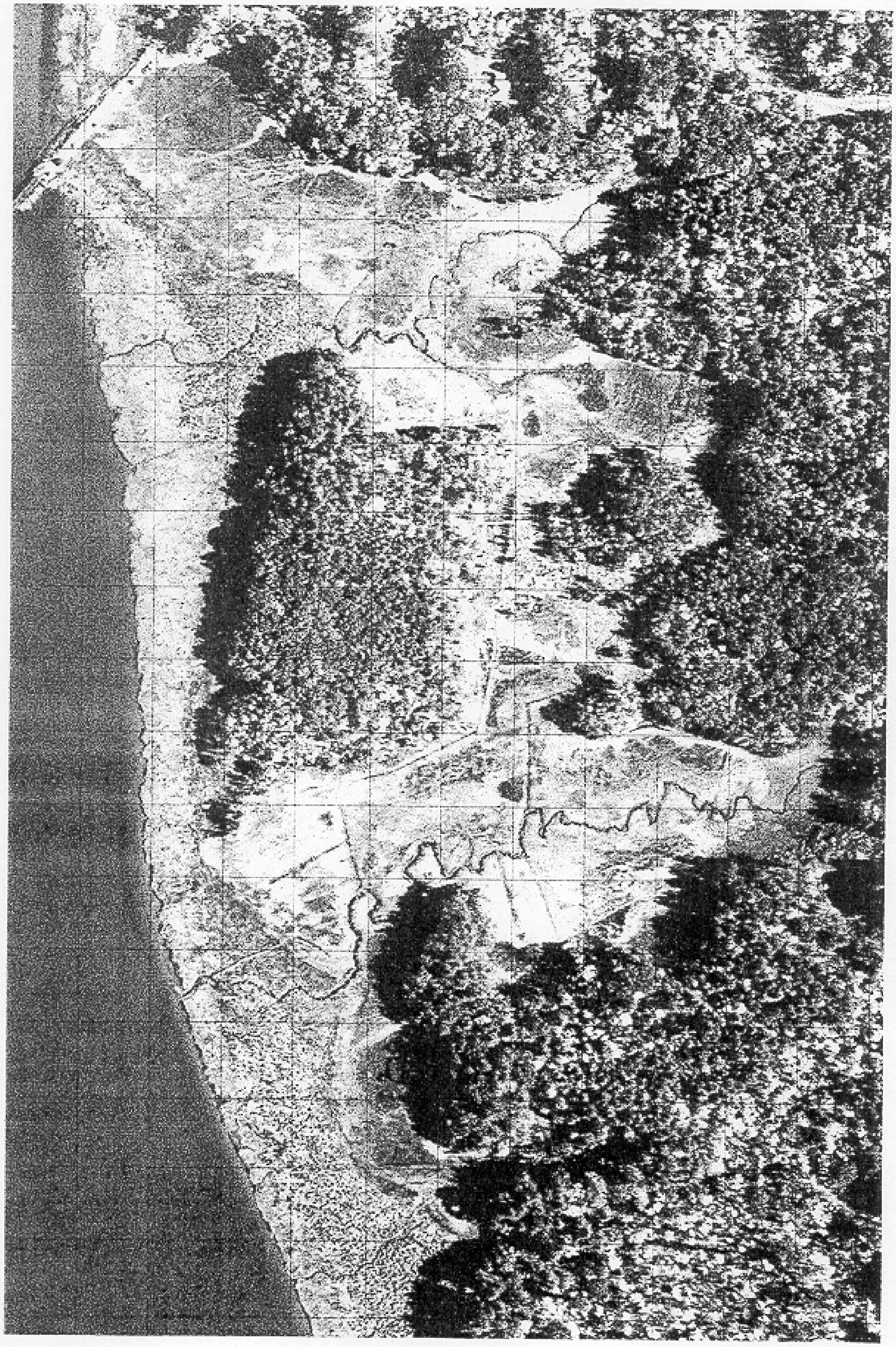


Figure 7. 1995 image of site 2 - RR East.

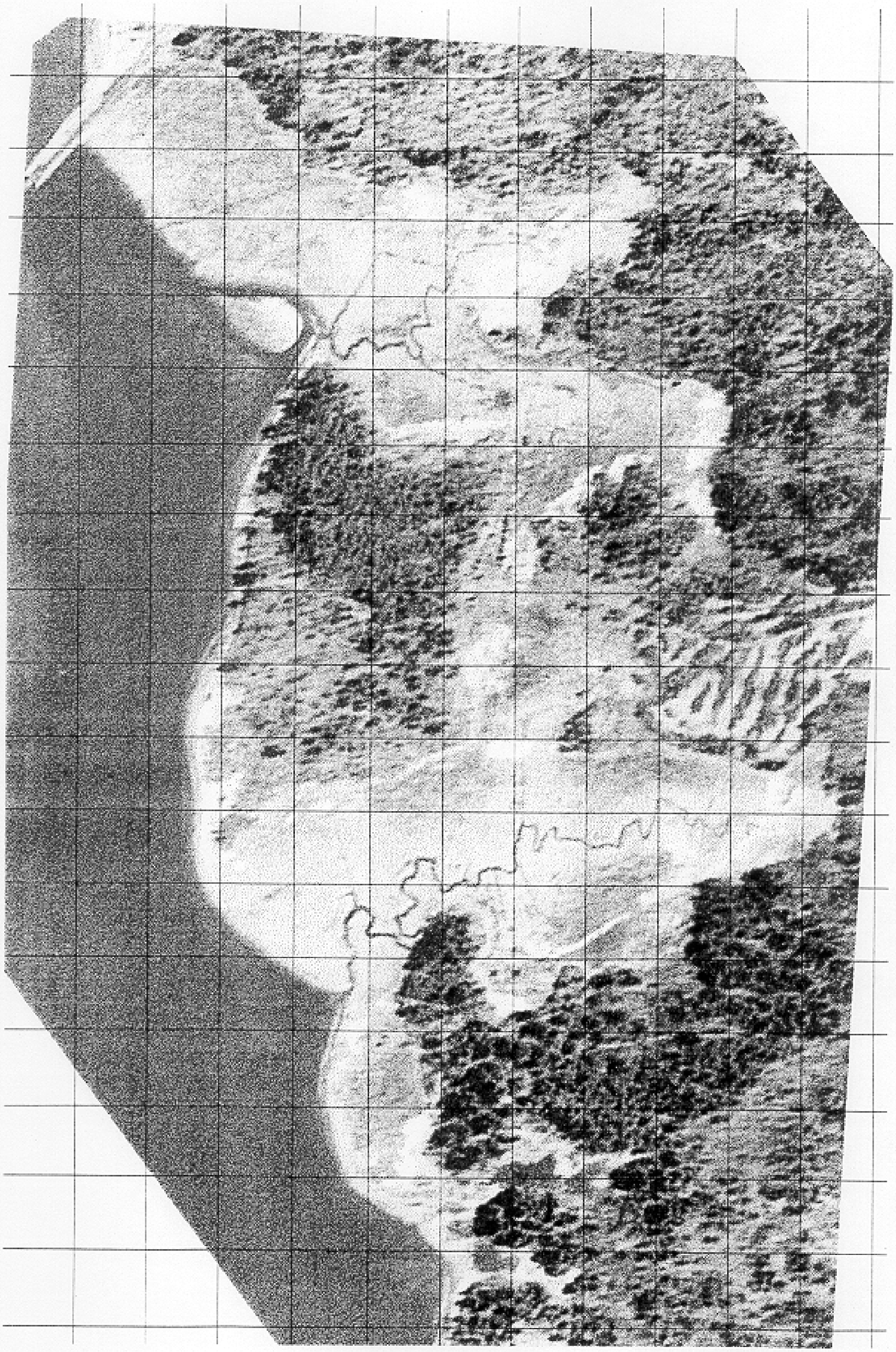
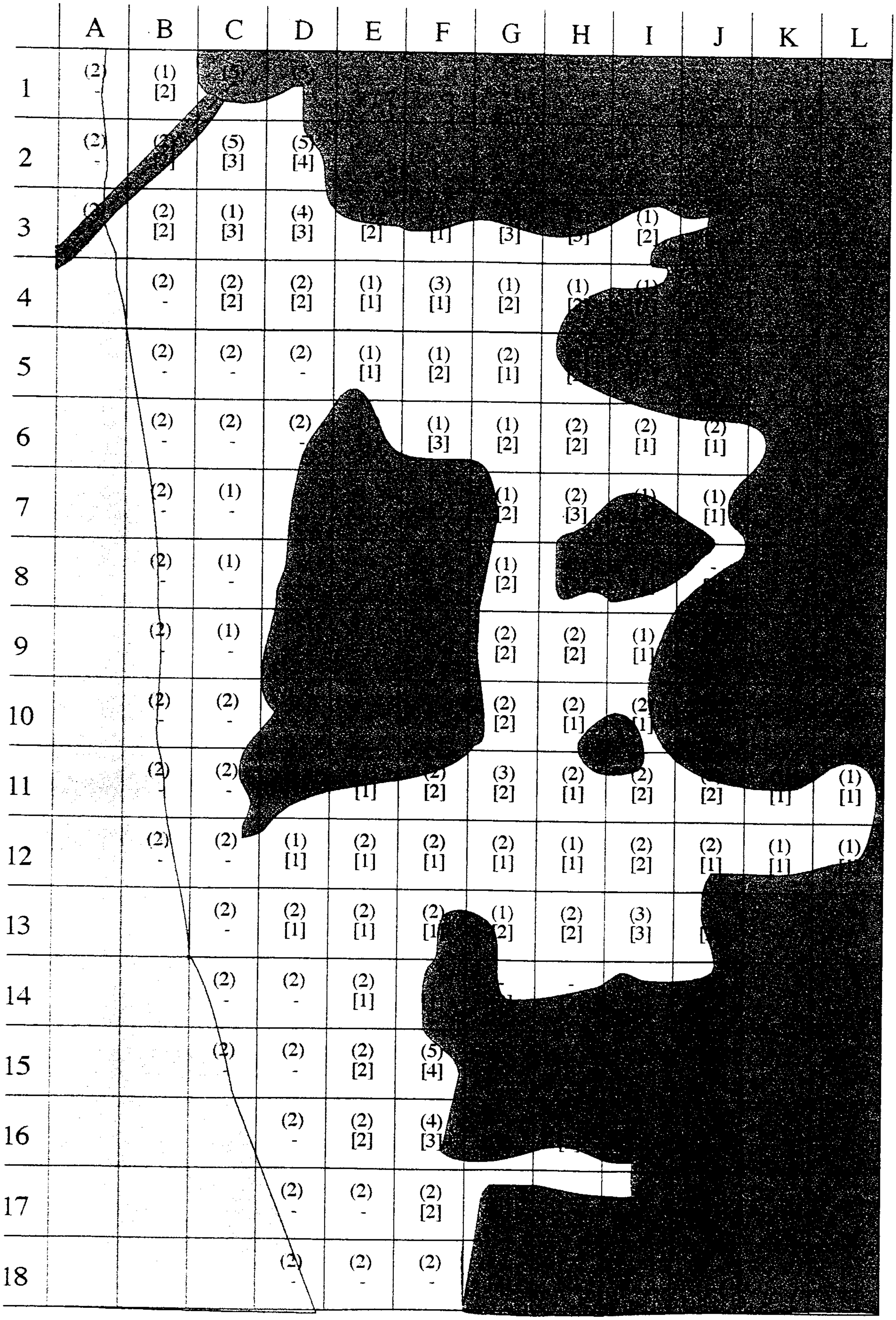


Figure 8. 1954 image of site 2 - RR East.

Site: RR East 1995/1954 TOP: (1995) BOTTOM: [1954]



	A	B	C	D	E	F	G	H	I	J	K	L
1	(2) -	(1) [2]										
2	(2) -	(2)	(5) [3]	(5) [4]								
3	(2)	(2) [2]	(1) [3]	(4) [3]	[2]	[1]	[3]		(1) [2]			
4		(2) -	(2) [2]	(2) [2]	(1) [1]	(3) [1]	(1) [2]	(1)	(1)			
5		(2) -	(2) -	(2) -	(1) [1]	(1) [2]	(2) [1]					
6		(2) -	(2) -	(2) -		(1) [3]	(1) [2]	(2) [2]	(2) [1]	(2) [1]		
7		(2) -	(1) -				(1) [2]	(2) [3]	(1)	(1) [1]		
8		(2) -	(1) -				(1) [2]			-		
9		(2) -	(1) -				(2) [2]	(2) [2]	(1) [1]			
10		(2) -	(2) -				(2) [2]	(2) [1]	(2) [1]			
11		(2) -	(2) -		[1]	(2) [2]	(3) [2]	(2) [1]	(2) [2]	[2]	[1]	(1) [1]
12		(2) -	(2) -	(1) [1]	(2) [1]	(2) [1]	(2) [1]	(1) [1]	(2) [2]	(2) [1]	(1) [1]	(1)
13			(2) -	(2) [1]	(2) [1]	(2) [1]	(1) [2]	(2) [2]	(3) [3]			
14			(2) -	(2) -	(2) [1]		-	-				
15			(2) -	(2) -	(2) [2]	(5) [4]						
16				(2) -	(2) [2]	(4) [3]						
17				(2) -	(2) -	(2) [2]						
18				(2) -	(2) -	(2) -						

Figure 9. MCI analysis of site 2.

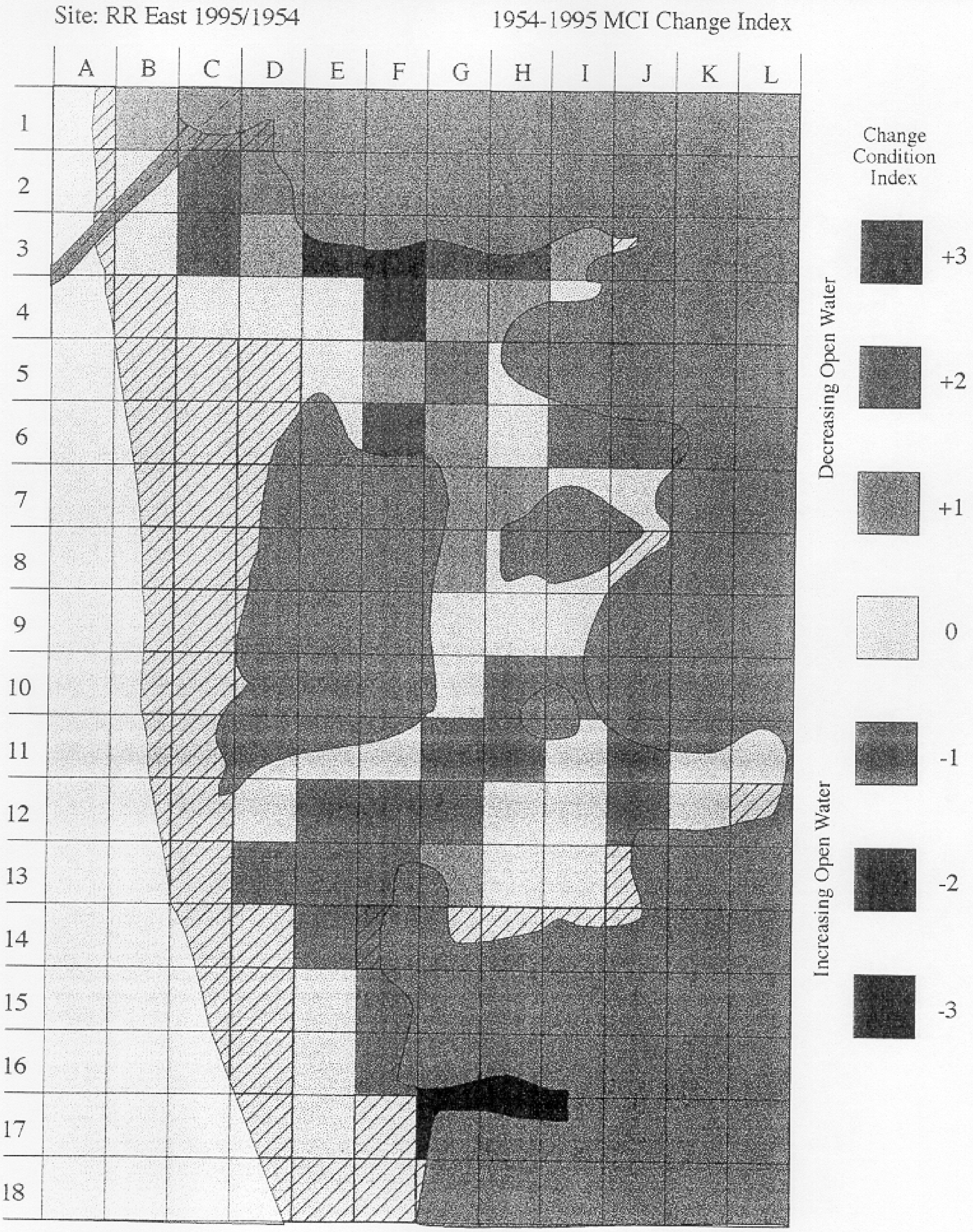


Figure 10. Trend analysis of site 2. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

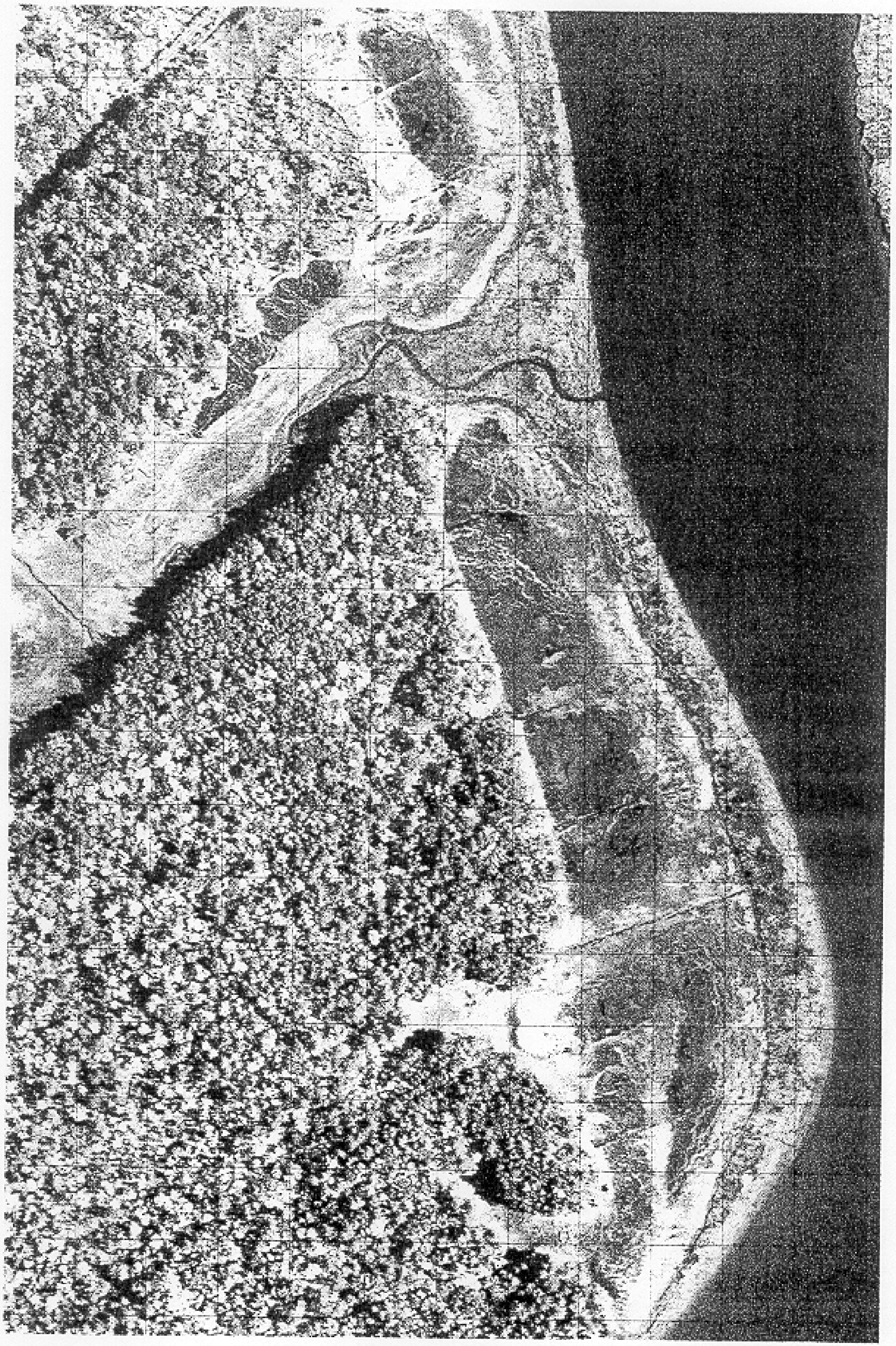


Figure 11. 1995 image of site 3 - RR Meander.

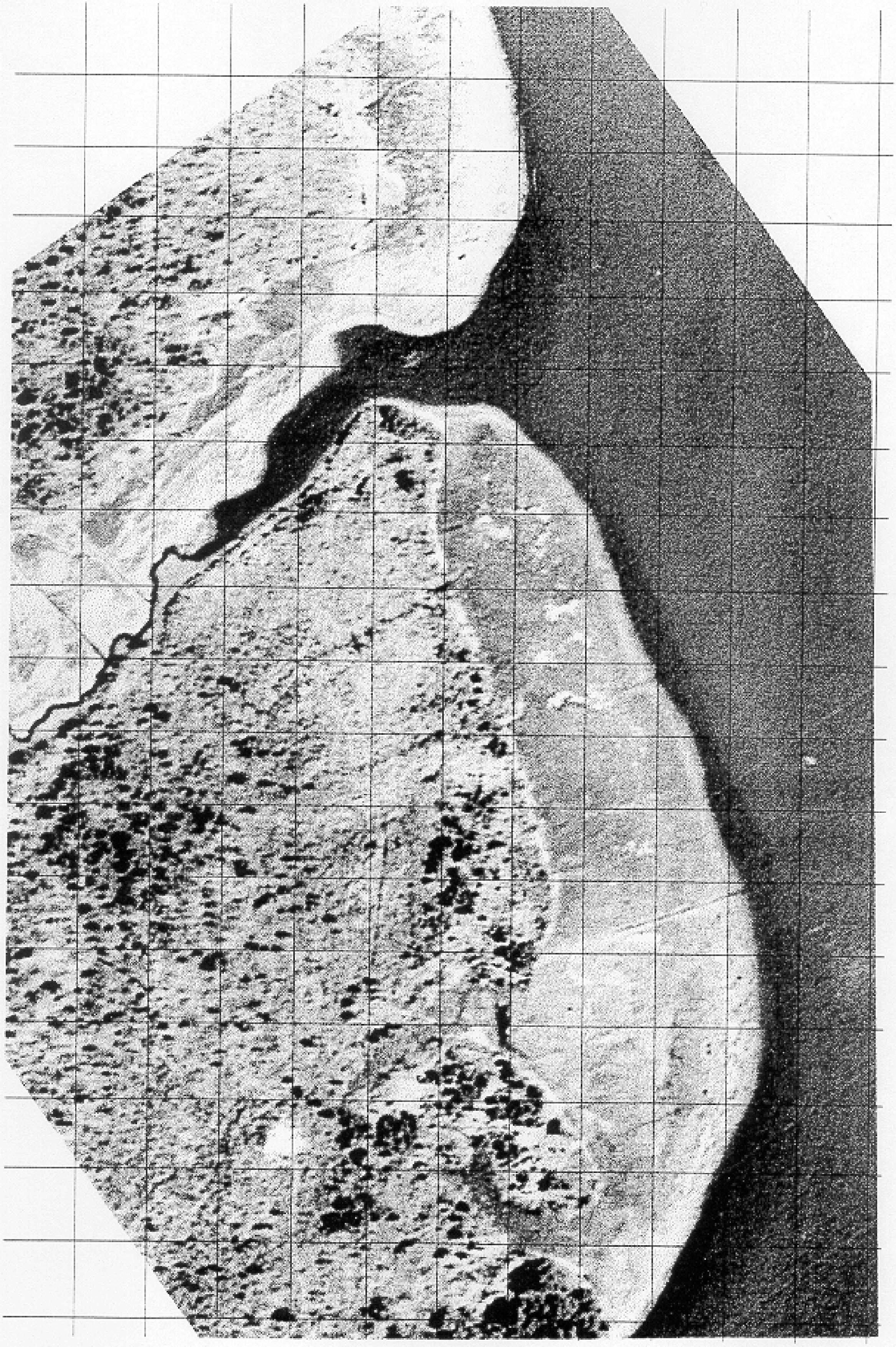
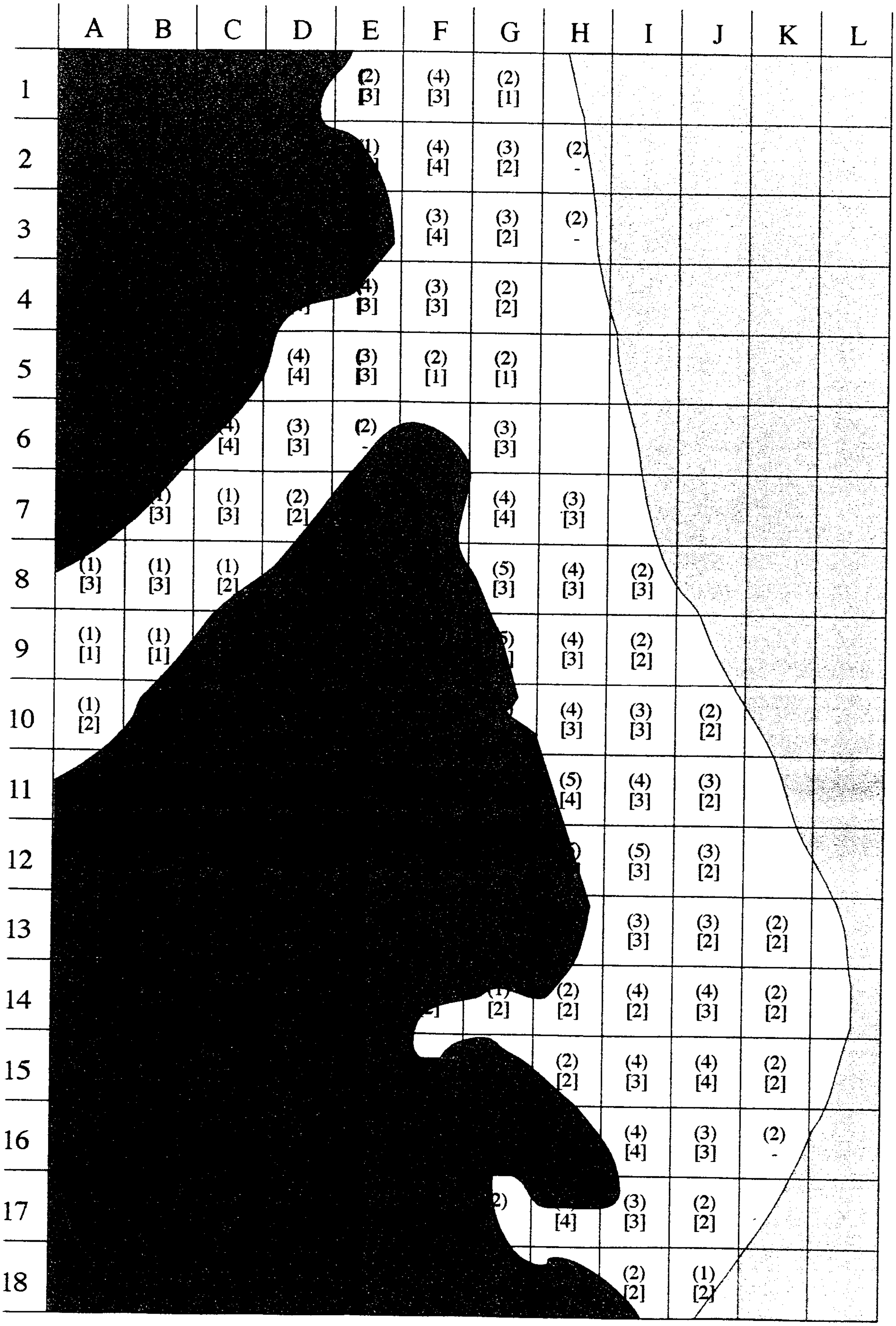


Figure 12. 1954 image of site 3 - RR Meander.

Site: RR Meander 1995/1954 TOP: (1995) BOTTOM: [1954]



	A	B	C	D	E	F	G	H	I	J	K	L
1					(2) [3]	(4) [3]	(2) [1]					
2					(1)	(4) [4]	(3) [2]	(2) -				
3						(3) [4]	(3) [2]	(2) -				
4				]	(4) [3]	(3) [3]	(2) [2]					
5				(4) [4]	(3) [3]	(2) [1]	(2) [1]					
6			4) [4]	(3) [3]	(2) -		(3) [3]					
7		1) [3]	(1) [3]	(2) [2]			(4) [4]	(3) [3]				
8	(1) [3]	(1) [3]	(1) [2]				(5) [3]	(4) [3]	(2) [3]			
9	(1) [1]	(1) [1]					5)	(4) [3]	(2) [2]			
10	(1) [2]							(4) [3]	(3) [3]	(2) [2]		
11								(5) [4]	(4) [3]	(3) [2]		
12									(5) [3]	(3) [2]		
13									(3) [3]	(3) [2]	(2) [2]	
14							[2]	(2) [2]	(4) [2]	(4) [3]	(2) [2]	
15								(2) [2]	(4) [3]	(4) [4]	(2) [2]	
16									(4) [4]	(3) [3]	(2) -	
17							2)	[4]	(3) [3]	(2) [2]		
18									(2) [2]	(1) [2]		

Figure 13. MCI analysis of site 3.

Site: RR Meander 1995/1954

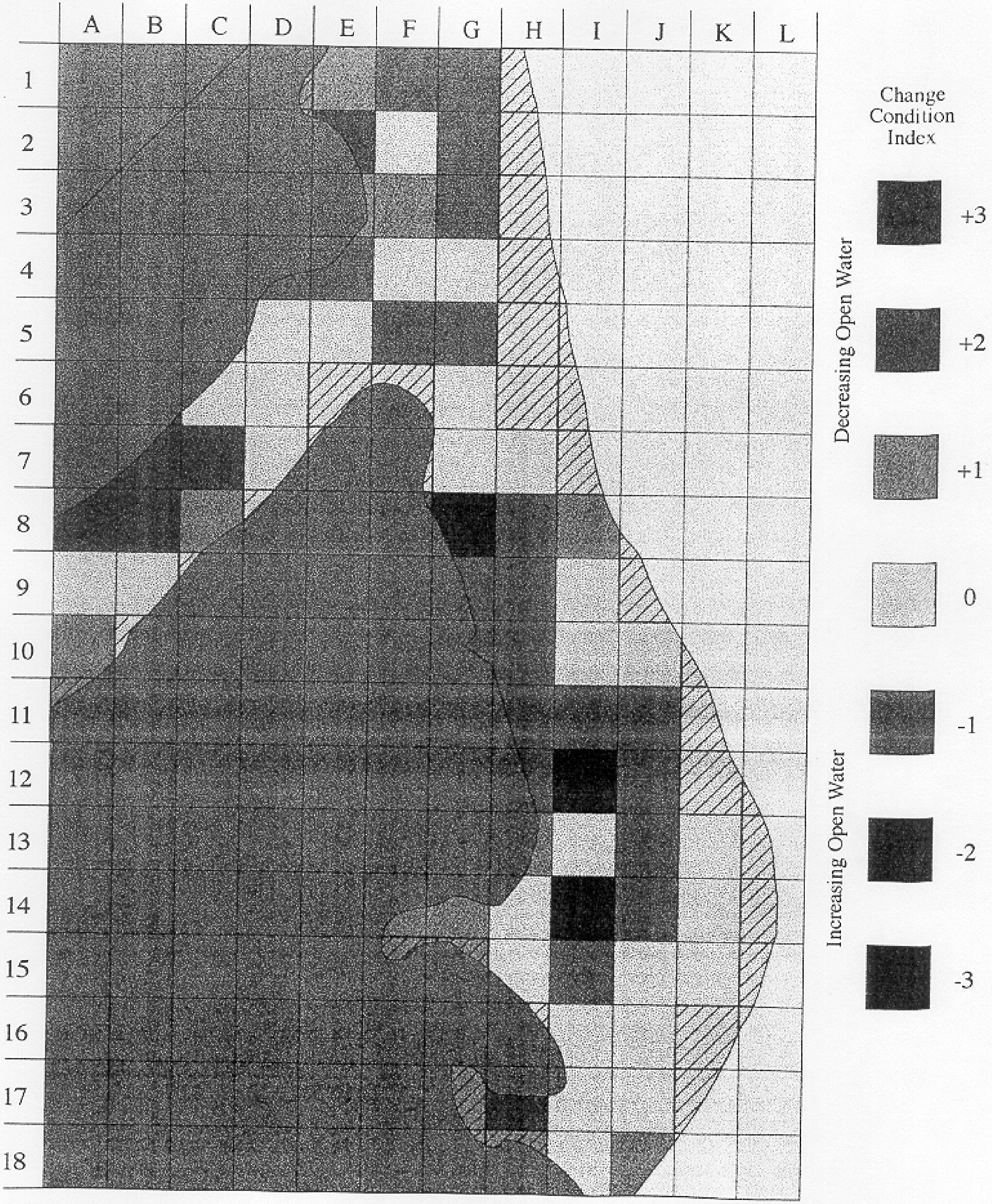


Figure 14. Trend analysis of site 3. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

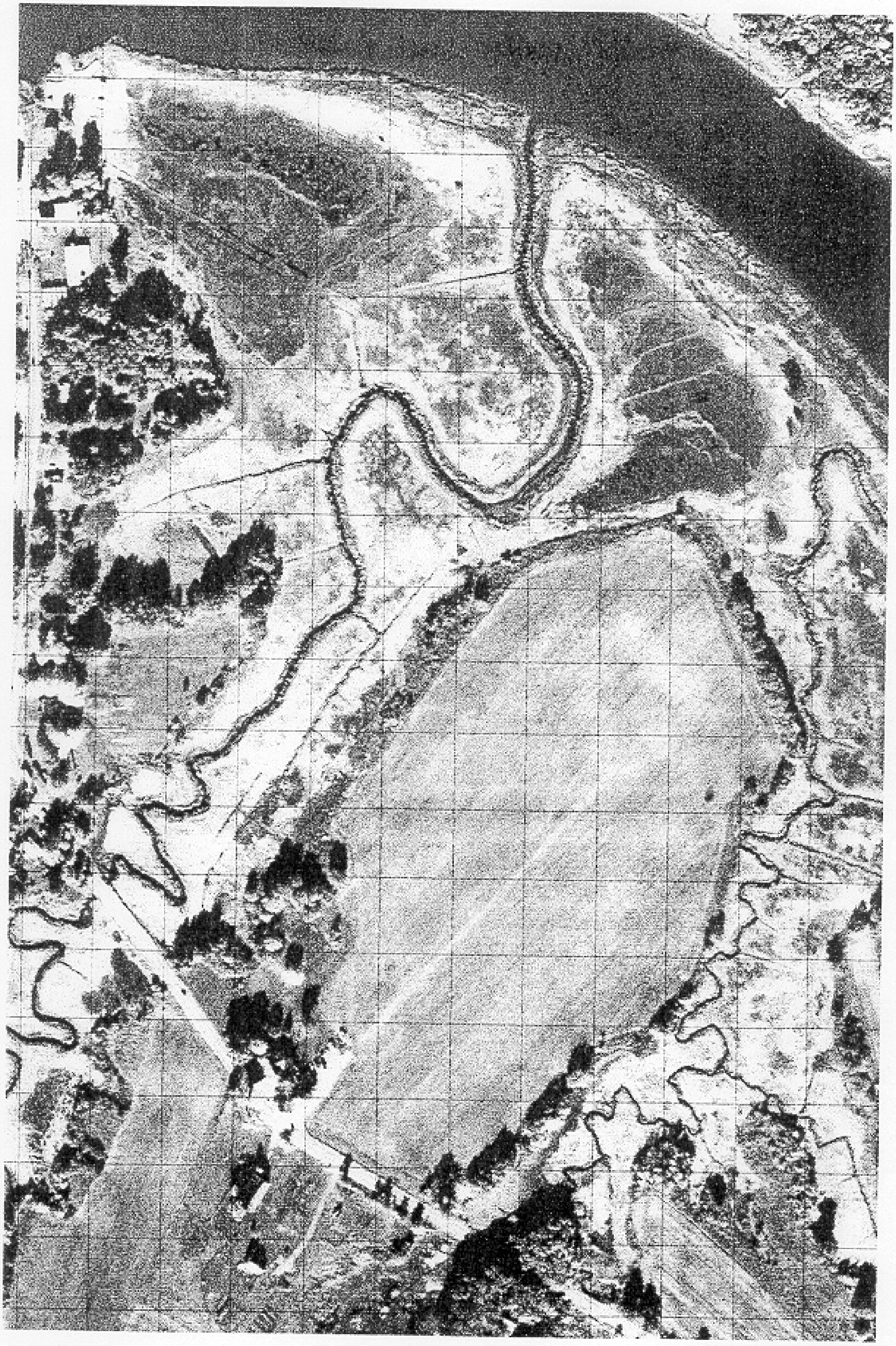


Figure 15. 1995 image of site 4 - Chapmans Landing.

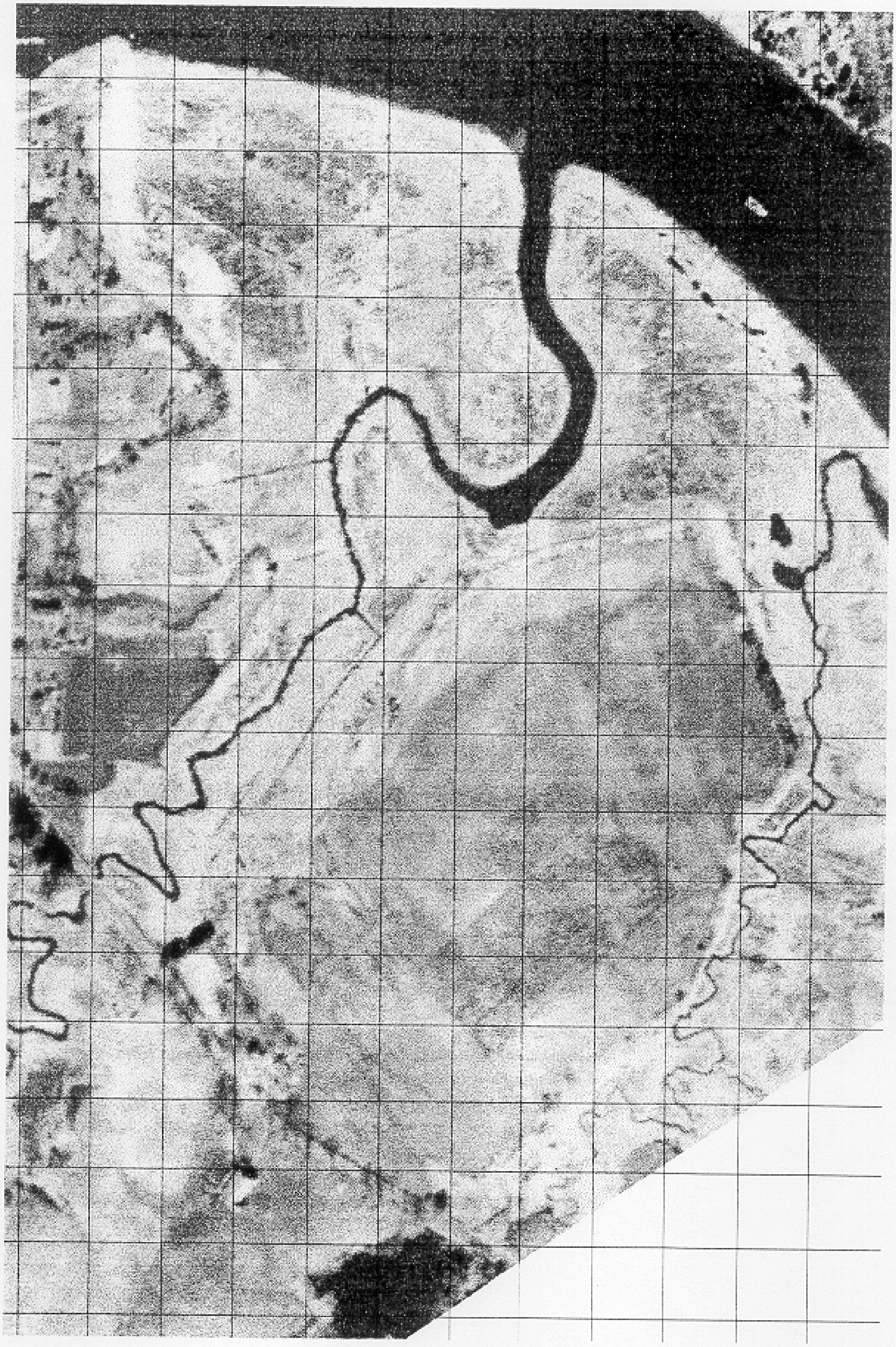


Figure 16. 1954 image of site 4 - Chapmans Landing.

Site: Chapmans Landing 1995/1954 Top:(1995) Bottom:[1954]

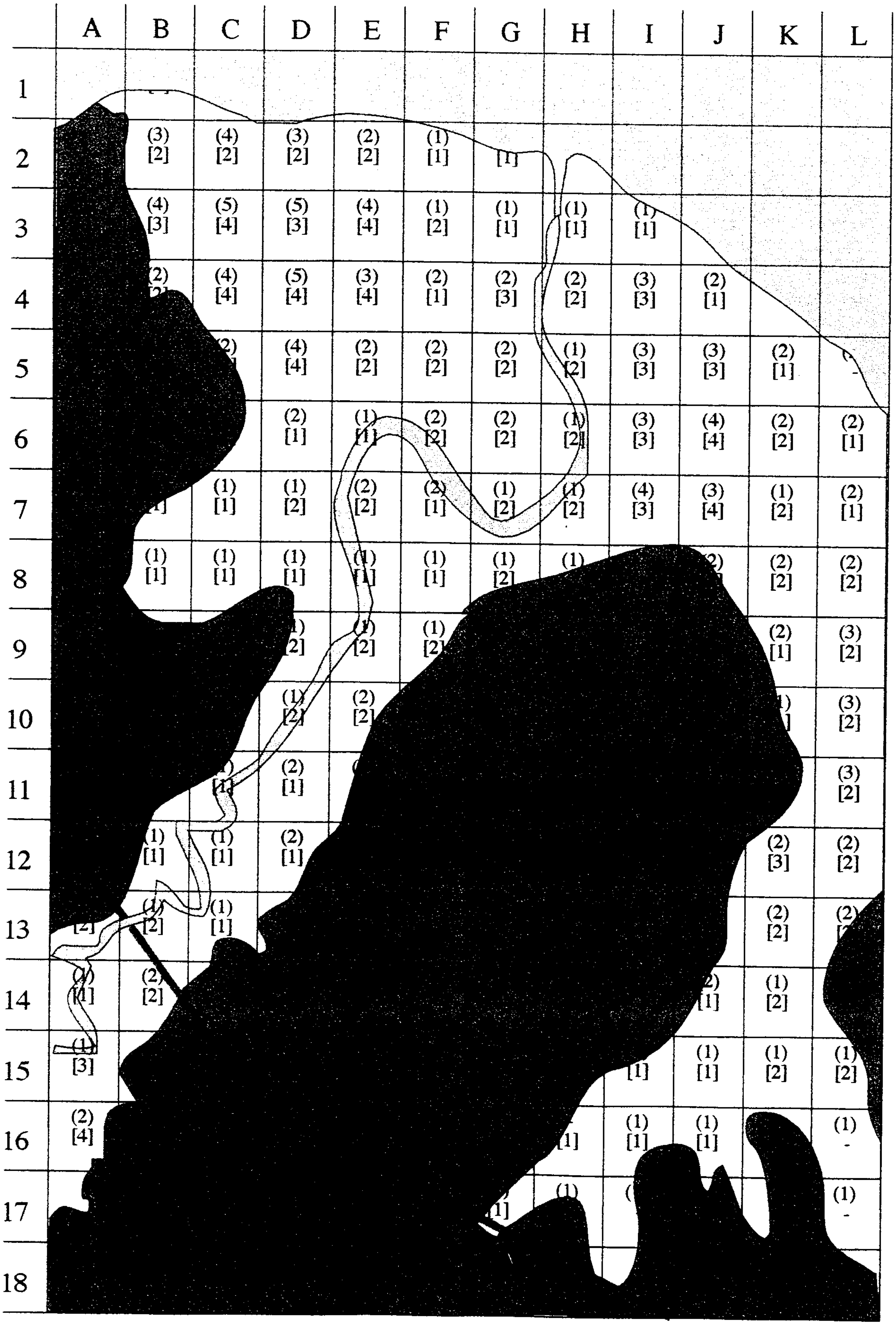


Figure 17. MCI analysis of site 4.

Site: Chapmans Landing

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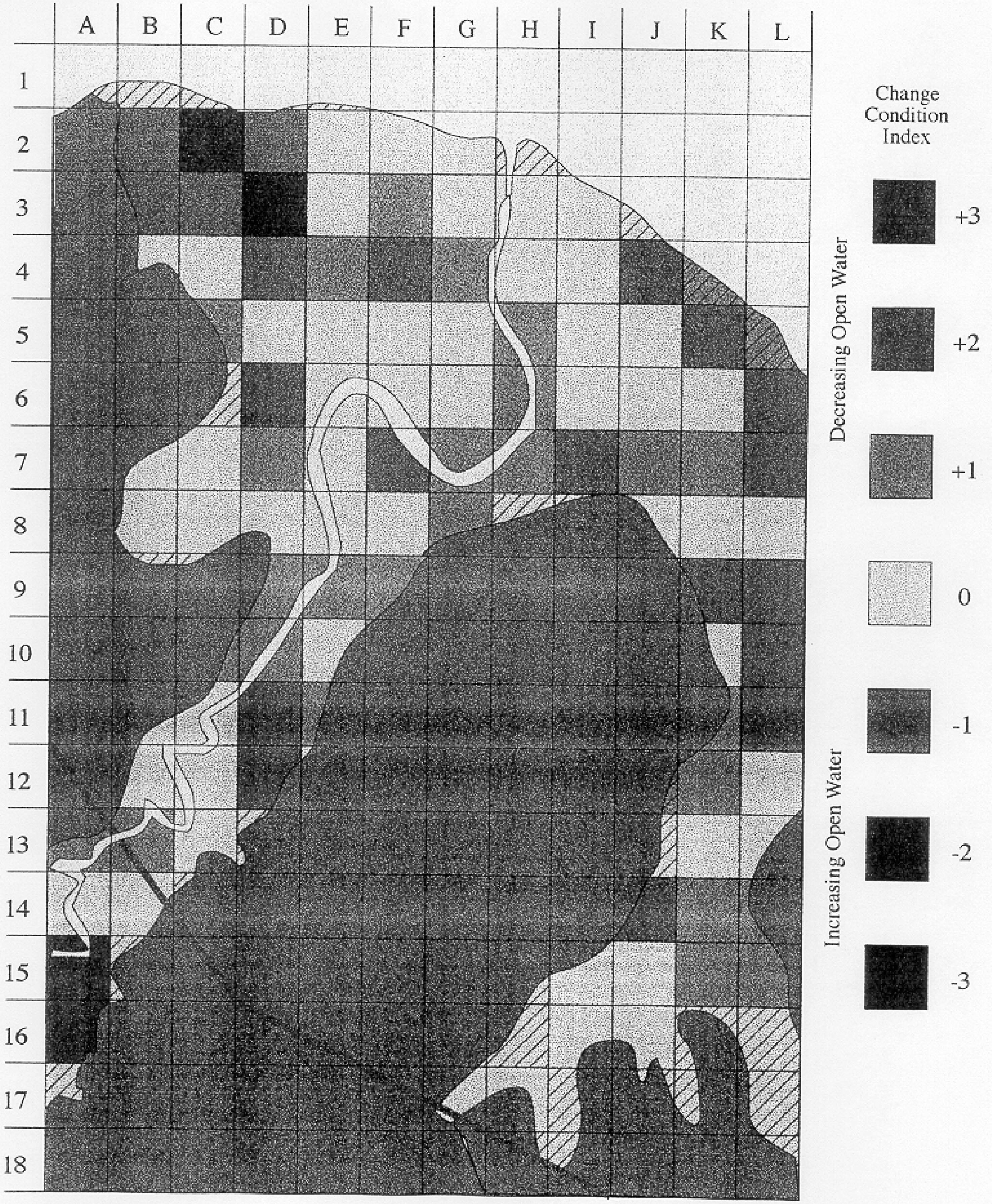


Figure 18. Trend analysis of site 4. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

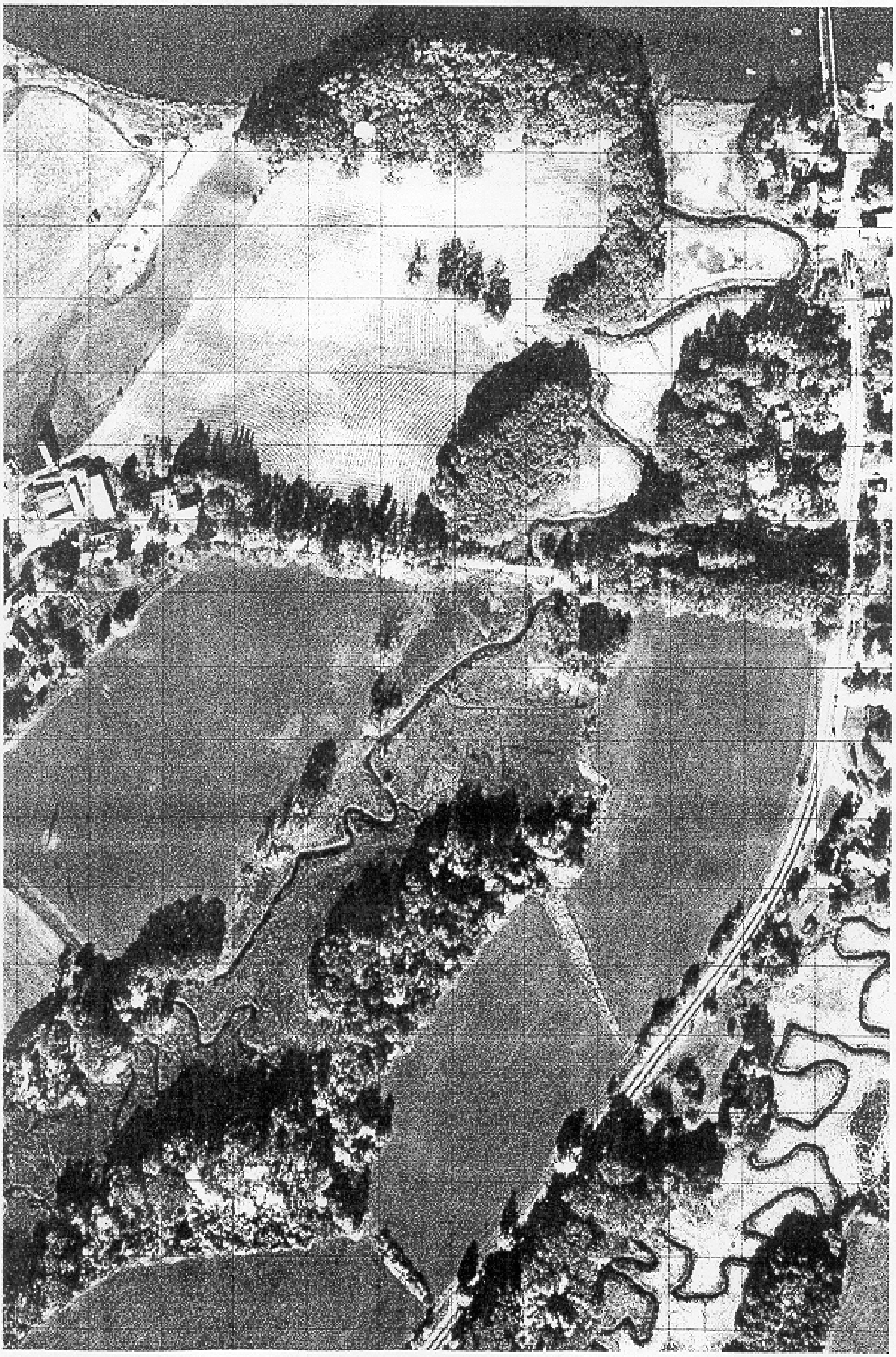


Figure 19. 1995 image of site 5 - Stuart Farm.

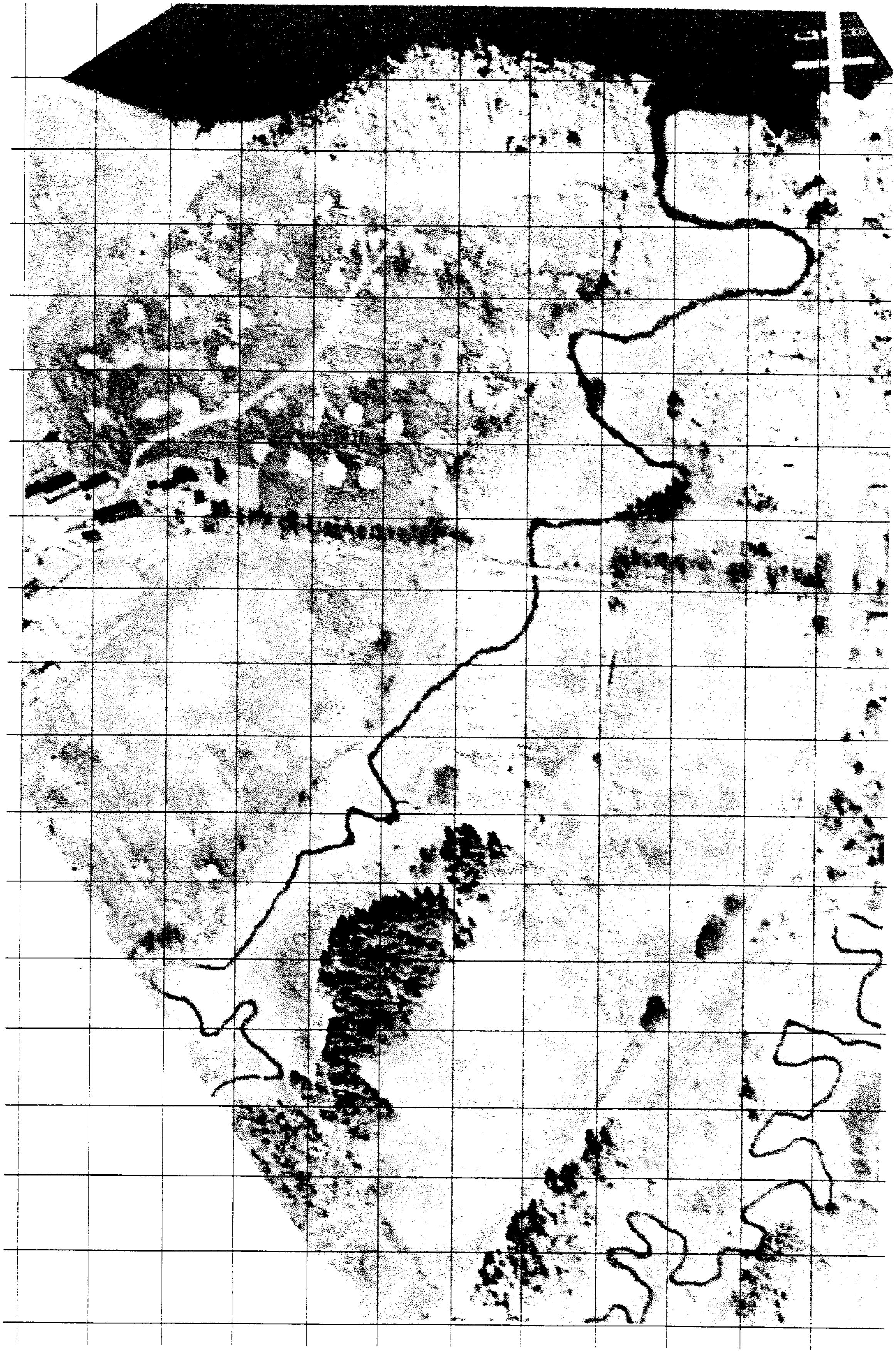
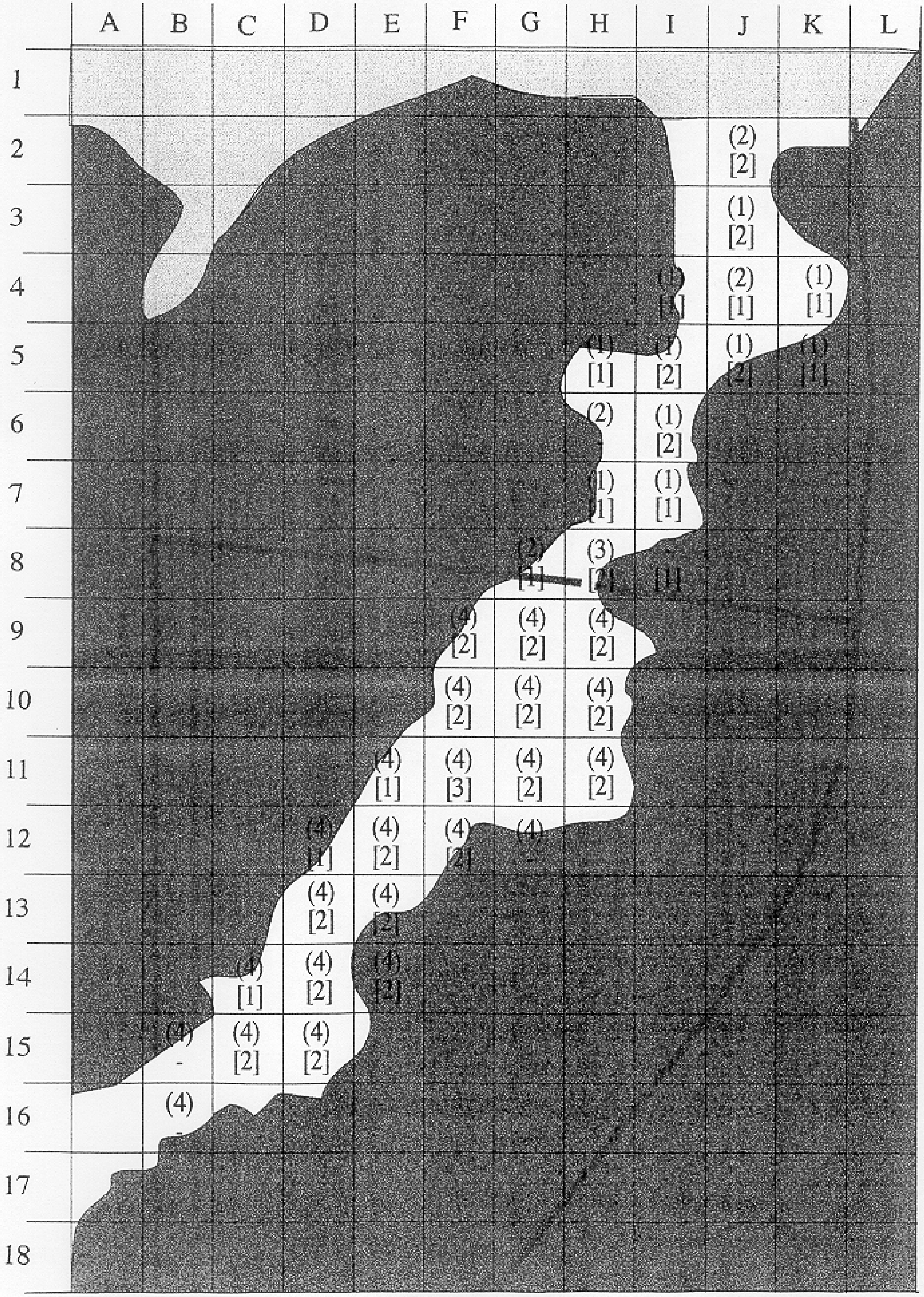


Figure 20. 1954 image of site 5 - Stuart Farm.

Figure 21. MCI analysis of site 5.

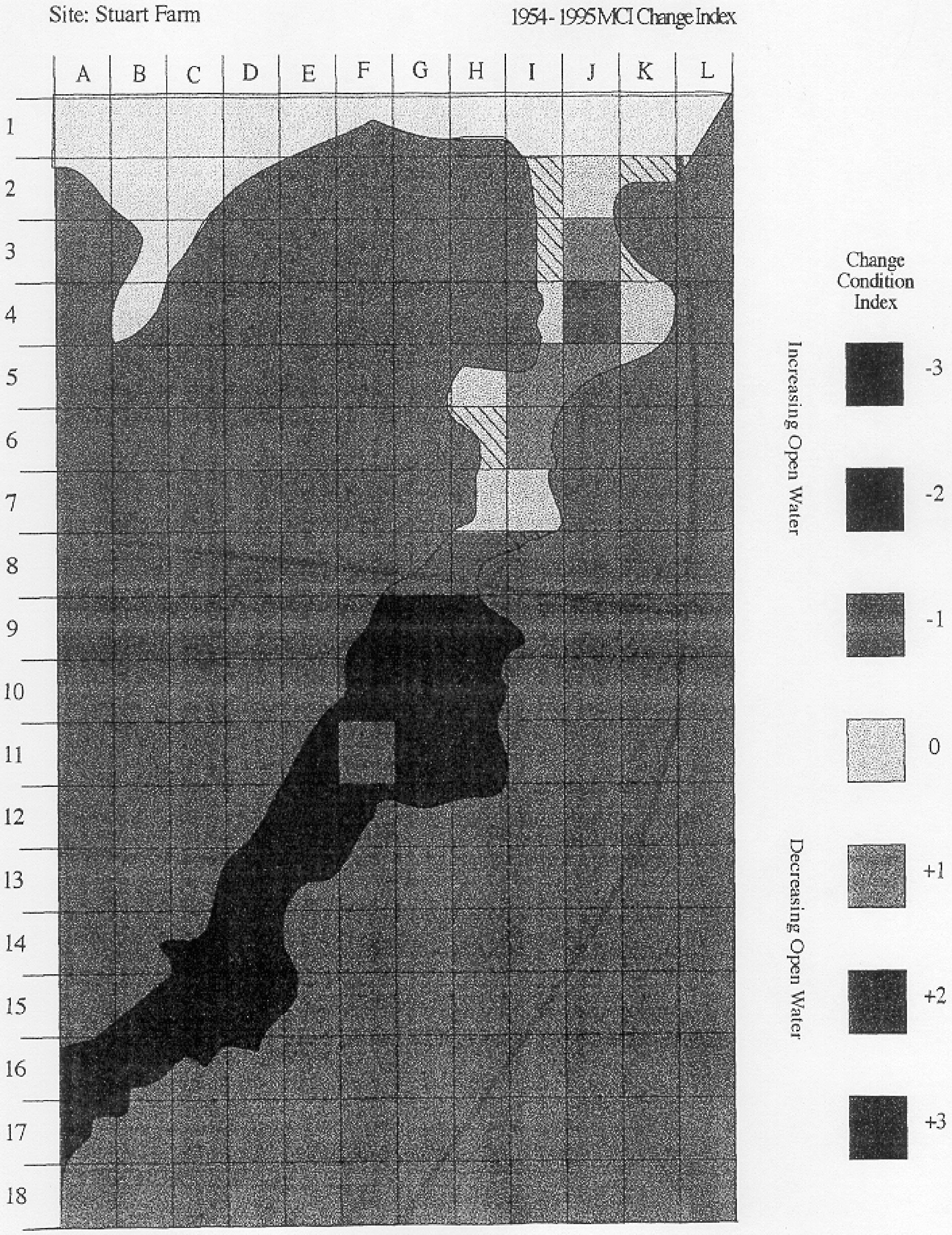
Site: Stuart Farm 1995/1954

Top: (1995) Bottom:[1954]



	A	B	C	D	E	F	G	H	I	J	K	L
1												
2										(2) [2]		
3										(1) [2]		
4									(1) [1]	(2) [1]	(1) [1]	
5								(1) [1]	(1) [2]	(1) [2]	(1) [1]	
6								(2) -	(1) [2]			
7								(1) [1]	(1) [1]			
8							(2) [1]	(3) [2]	- [1]			
9						(4) [2]	(4) [2]	(4) [2]				
10						(4) [2]	(4) [2]	(4) [2]				
11					(4) [1]	(4) [3]	(4) [2]	(4) [2]				
12				(4) [1]	(4) [2]	(4) [2]	(4) -					
13				(4) [2]	(4) [2]							
14			(4) [1]	(4) [2]	(4) [2]							
15		(4) -	(4) [2]	(4) [2]								
16		(4) -										
17												
18												

Figure 22. Trend analysis of site 5. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.



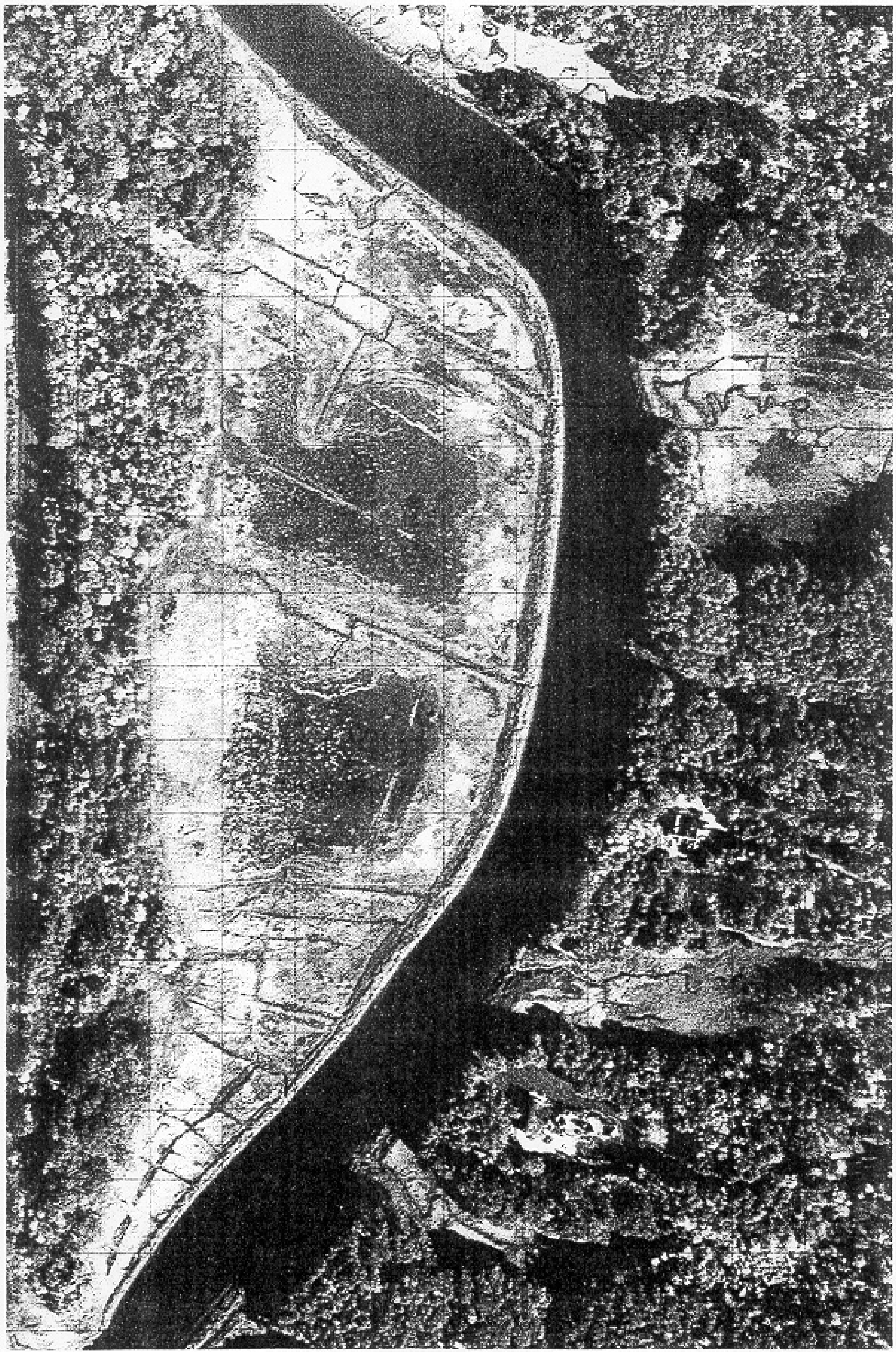


Figure 23. 1995 image of site 6 - Southern Meander.

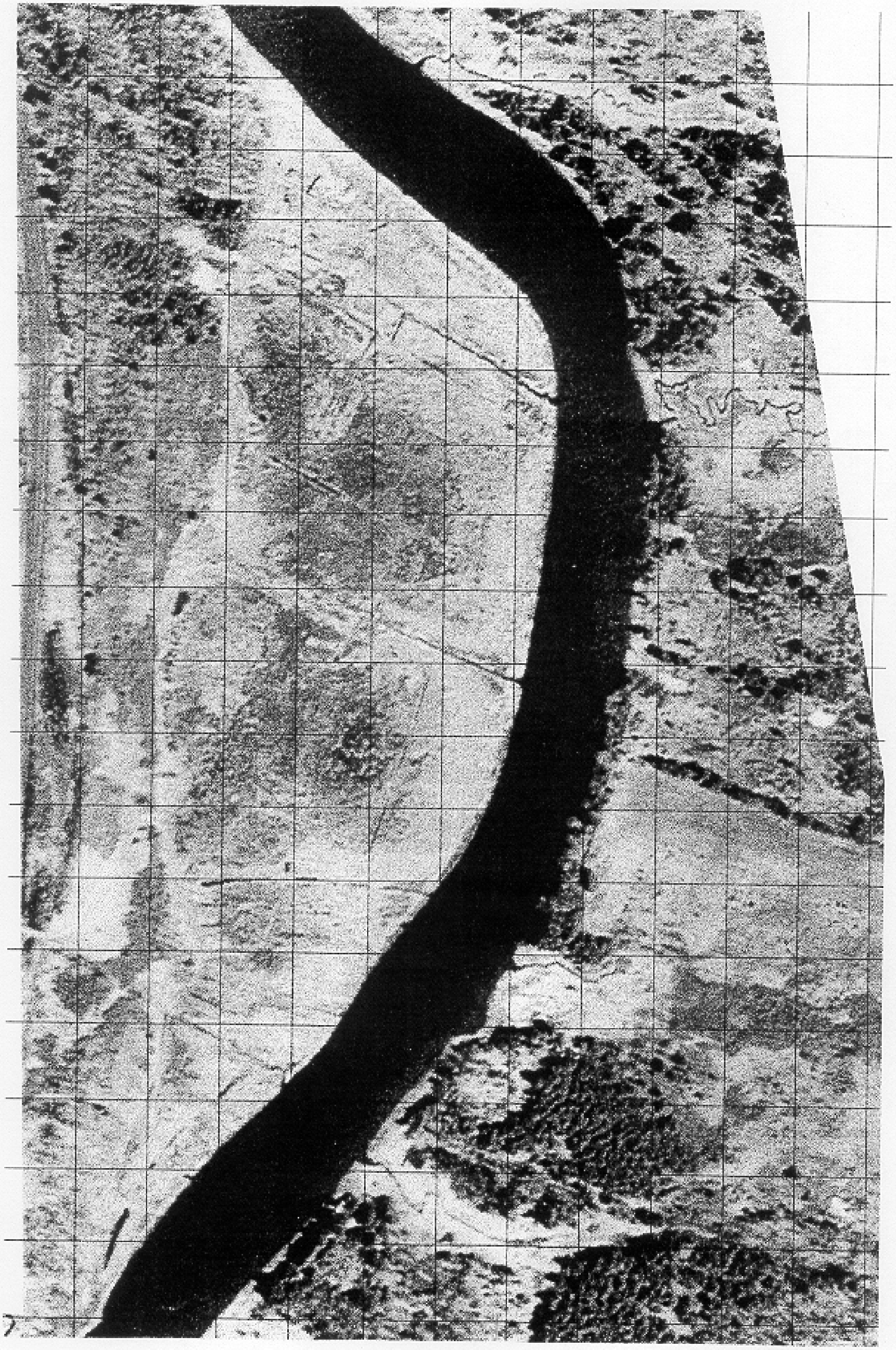
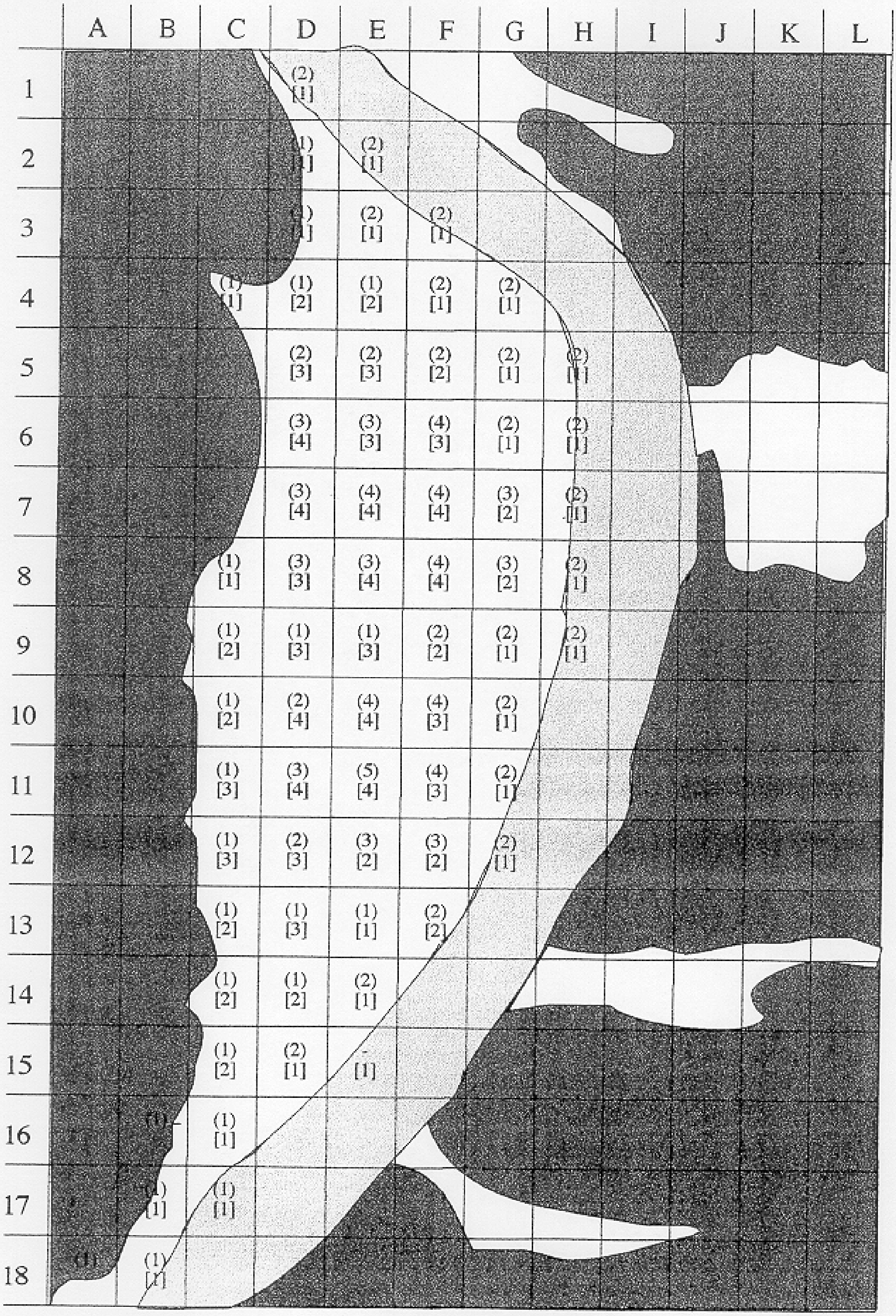


Figure 24. 1954 image of site 6 - Southern Meander.

Site: Southern Meander 1995/1954 TOP: (1995) BOTTOM: [1954]



	A	B	C	D	E	F	G	H	I	J	K	L
1				(2) [1]								
2				(1) [1]	(2) [1]							
3				(1) [1]	(2) [1]	(2) [1]						
4			(1) [1]	(1) [2]	(1) [2]	(2) [1]	(2) [1]					
5				(2) [3]	(2) [3]	(2) [2]	(2) [1]	(2) [1]				
6				(3) [4]	(3) [3]	(4) [3]	(2) [1]	(2) [1]				
7				(3) [4]	(4) [4]	(4) [4]	(3) [2]	(2) [1]				
8			(1) [1]	(3) [3]	(3) [4]	(4) [4]	(3) [2]	(2) [1]				
9			(1) [2]	(1) [3]	(1) [3]	(2) [2]	(2) [1]	(2) [1]				
10			(1) [2]	(2) [4]	(4) [4]	(4) [3]	(2) [1]					
11			(1) [3]	(3) [4]	(5) [4]	(4) [3]	(2) [1]					
12			(1) [3]	(2) [3]	(3) [2]	(3) [2]	(2) [1]					
13			(1) [2]	(1) [3]	(1) [1]	(2) [2]						
14			(1) [2]	(1) [2]	(2) [1]							
15			(1) [2]	(2) [1]	- [1]							
16		(1) -	(1) [1]									
17		(1) [1]	(1) [1]									
18	(1)	(1) [1]										

Figure 25. MCI analysis of site 6.

Site: Southern Meander

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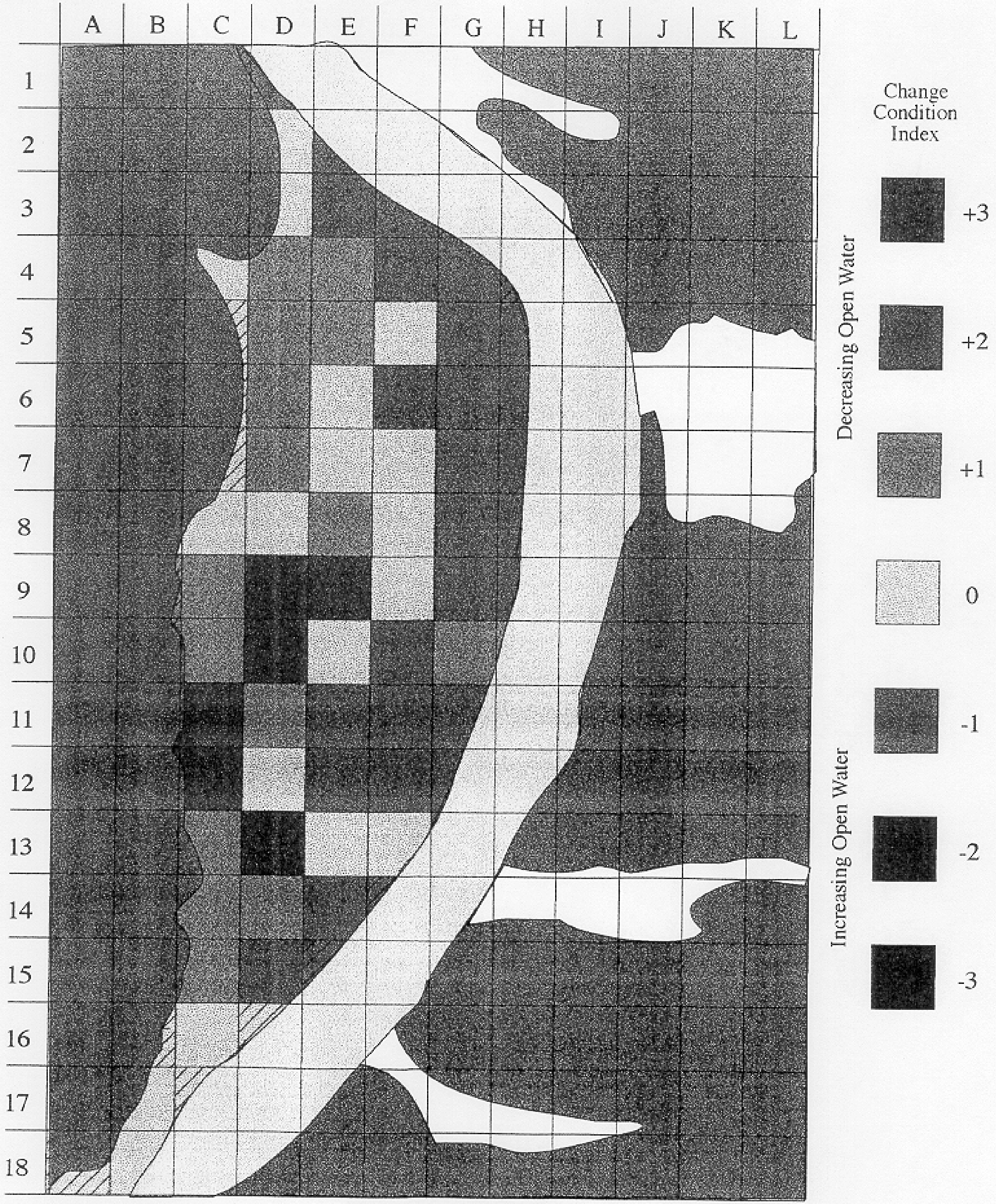


Figure 26. Trend analysis of site 6. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

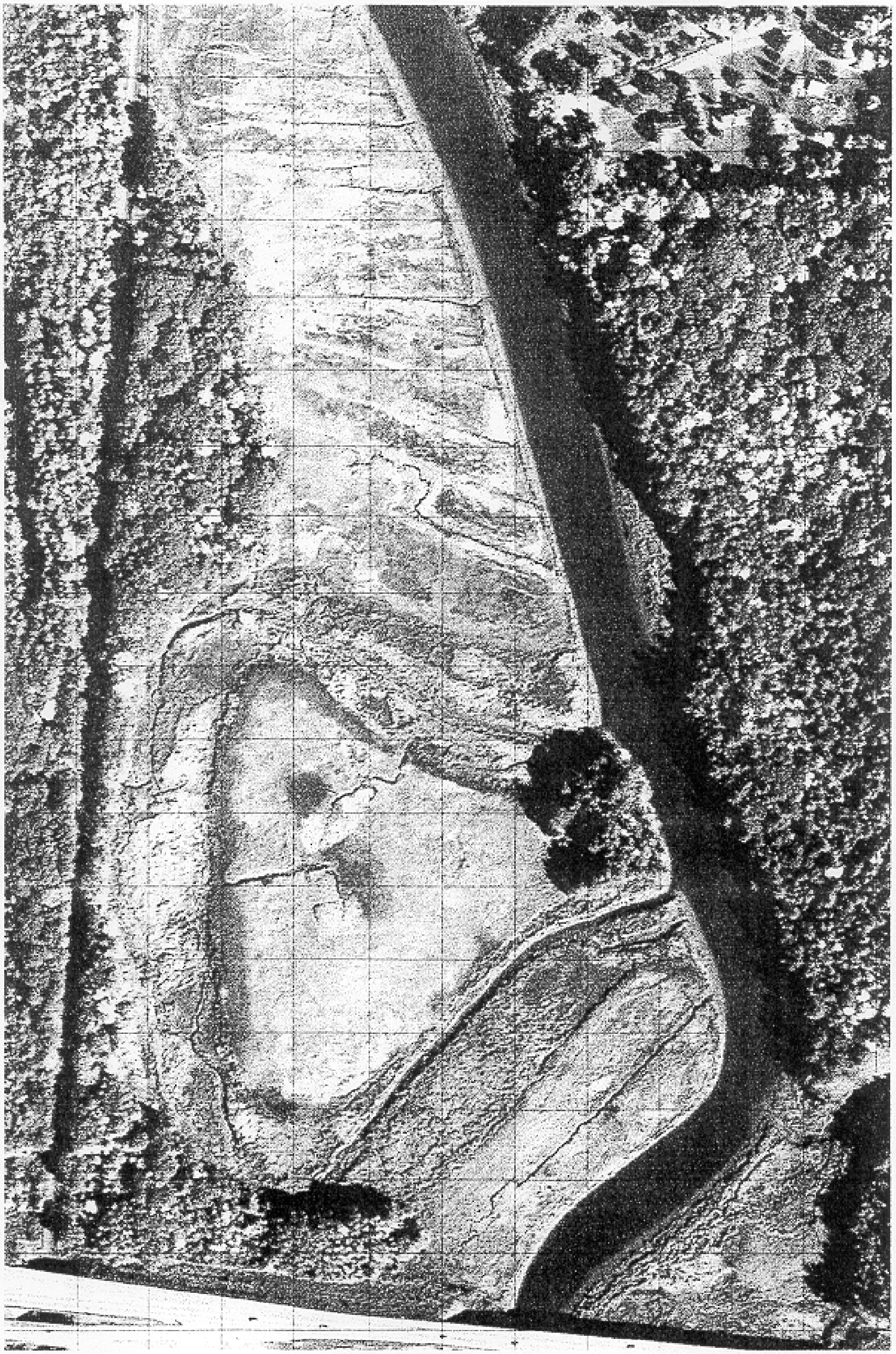


Figure 27. 1995 image of site 7 - Oxbow.

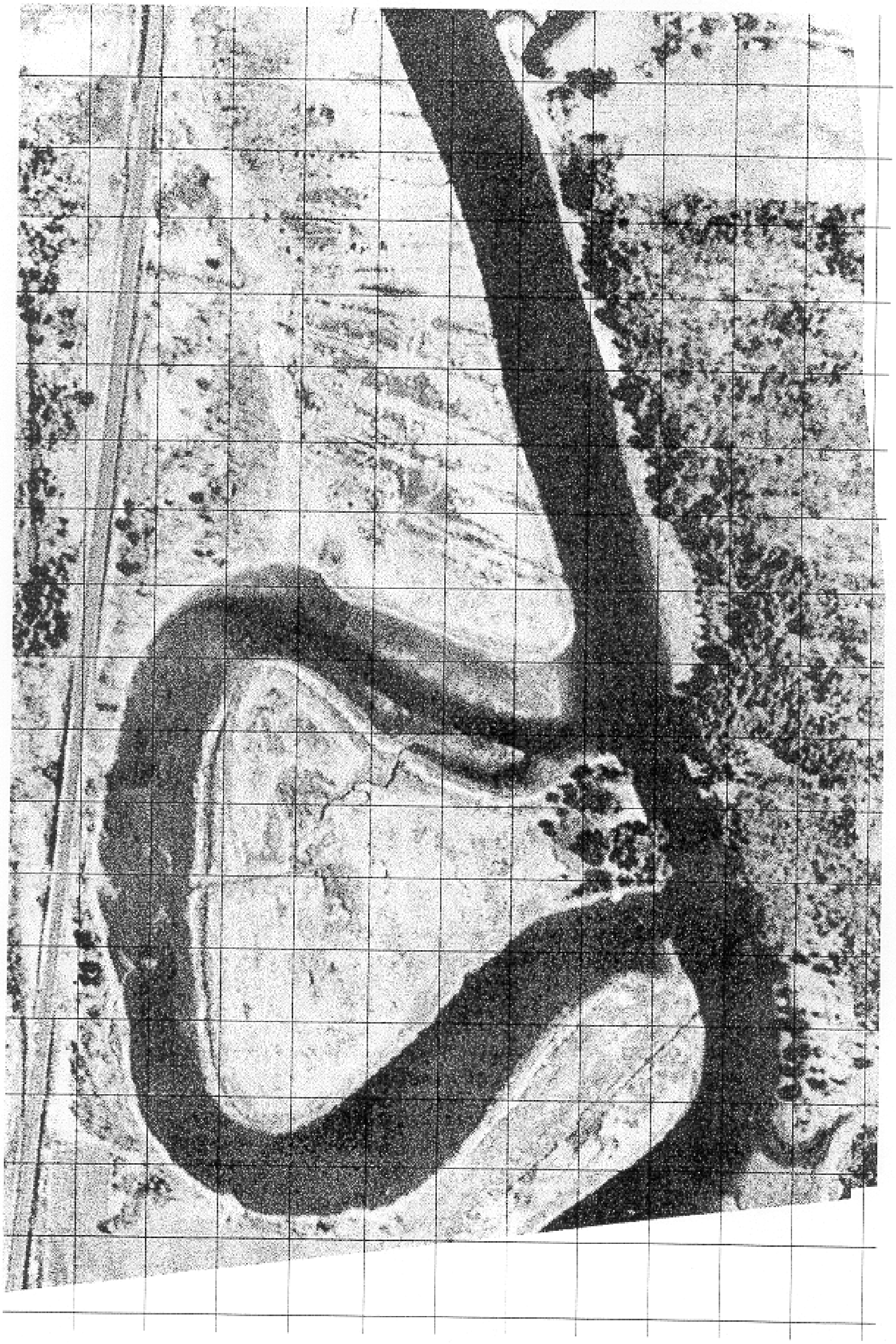
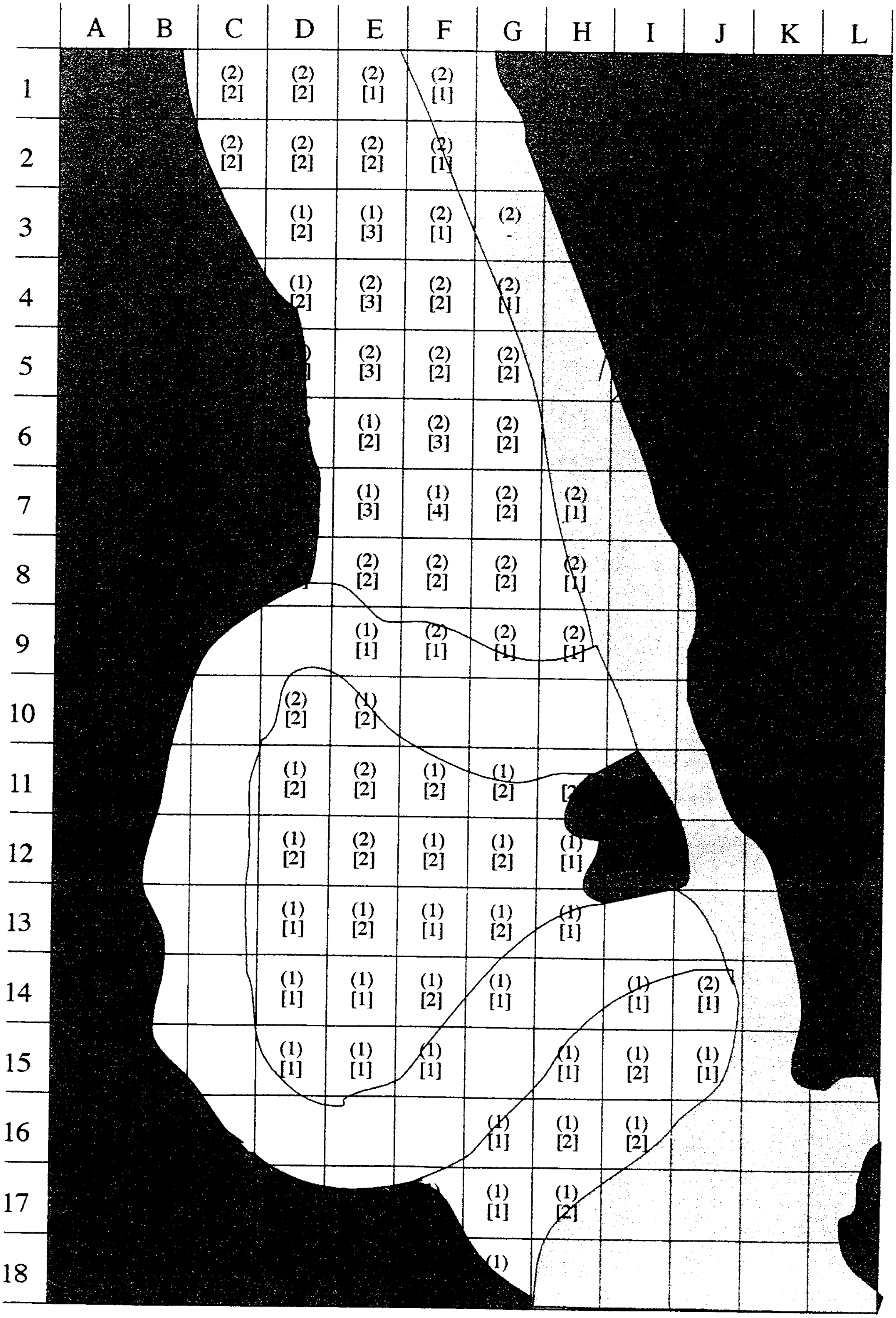


Figure 28. 1954 image of site 7 - Oxbow.

Site: Northern Oxbow 1995/1954 TOP: (1995) BOTTOM: [1954]



	A	B	C	D	E	F	G	H	I	J	K	L
1			(2) [2]	(2) [2]	(2) [1]	(2) [1]						
2			(2) [2]	(2) [2]	(2) [2]	(2) [1]						
3				(1) [2]	(1) [3]	(2) [1]	(2) -					
4				(1) [2]	(2) [3]	(2) [2]	(2) [1]					
5				[illegible]	(2) [3]	(2) [2]	(2) [2]					
6					(1) [2]	(2) [3]	(2) [2]					
7					(1) [3]	(1) [4]	(2) [2]	(2) [1]				
8					(2) [2]	(2) [2]	(2) [2]	(2) [1]				
9					(1) [1]	(2) [1]	(2) [1]	(2) [1]				
10				(2) [2]	(1) [2]							
11				(1) [2]	(2) [2]	(1) [2]	(1) [2]	[2				
12				(1) [2]	(2) [2]	(1) [2]	(1) [2]	(1) [1]				
13				(1) [1]	(1) [2]	(1) [1]	(1) [2]	(1) [1]				
14				(1) [1]	(1) [1]	(1) [2]	(1) [1]		(1) [1]	(2) [1]		
15				(1) [1]	(1) [1]	(1) [1]		(1) [1]	(1) [2]	(1) [1]		
16							(1) [1]	(1) [2]	(1) [2]			
17							(1) [1]	(1) [2]				
18							(1)					

Figure 29. MCI analysis of site 7.

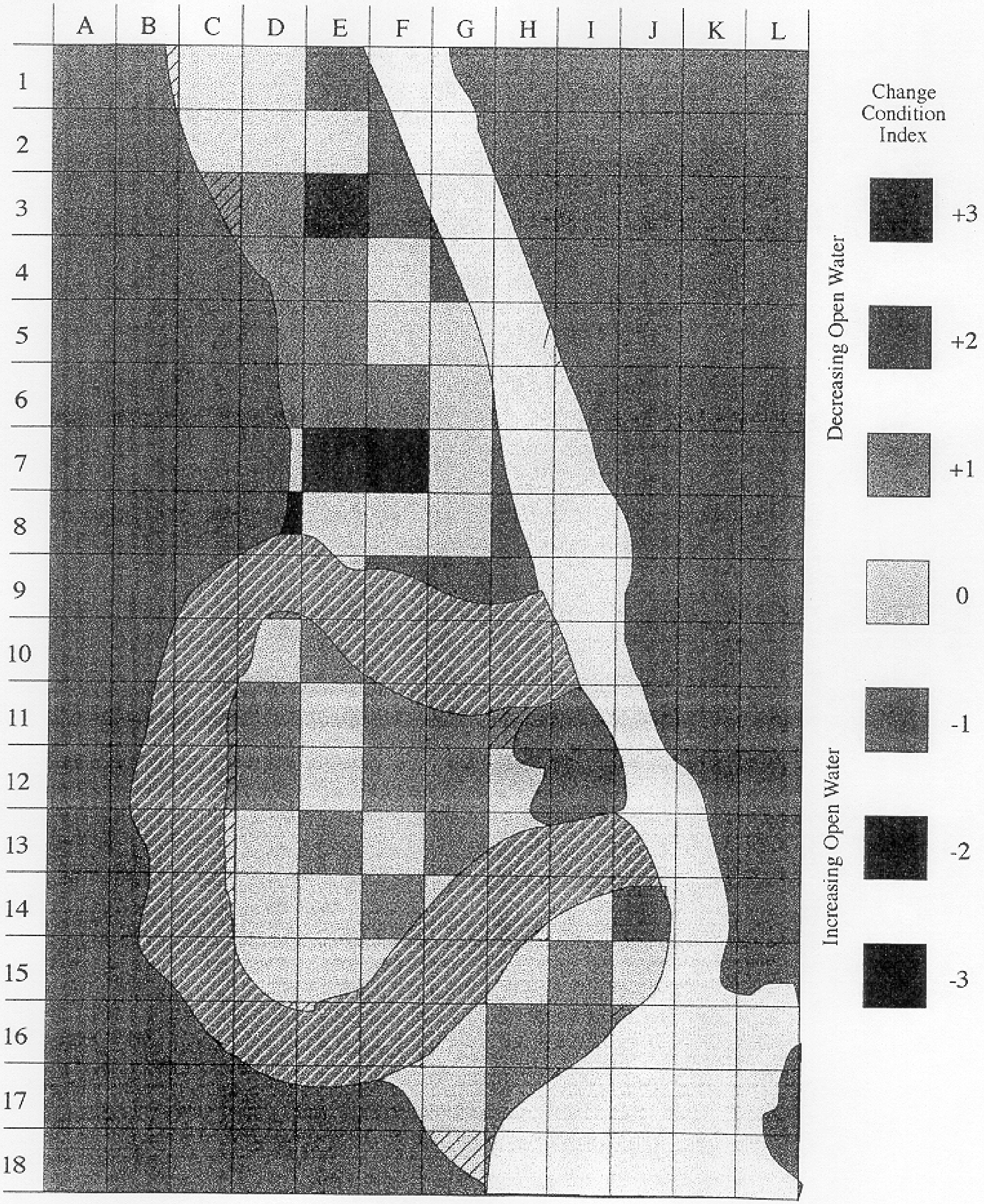


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Figure 30. Trend analysis of site 7. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

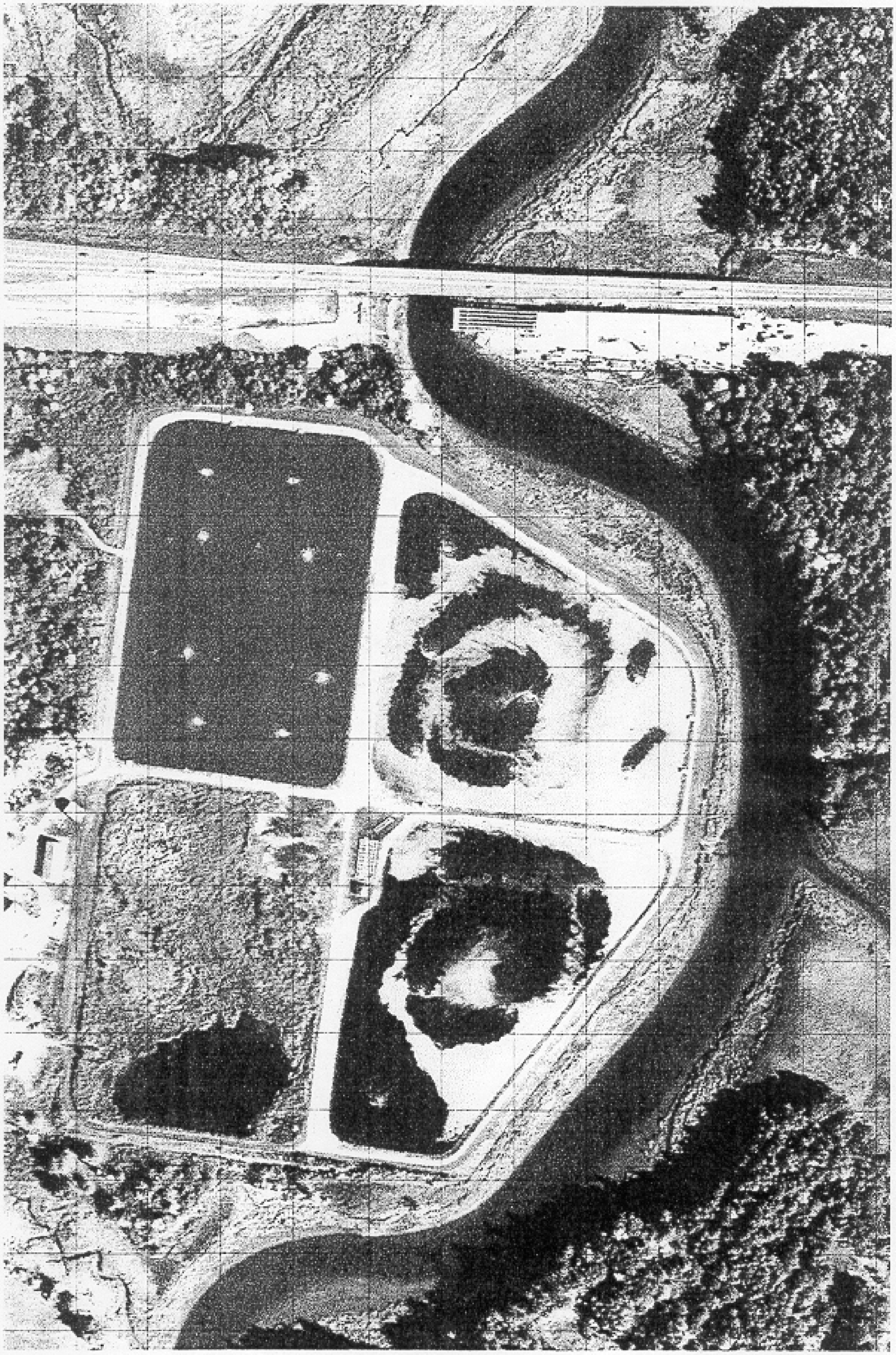

Figure 31. 1995 image of site 8 - Sewage Treatment Plant.

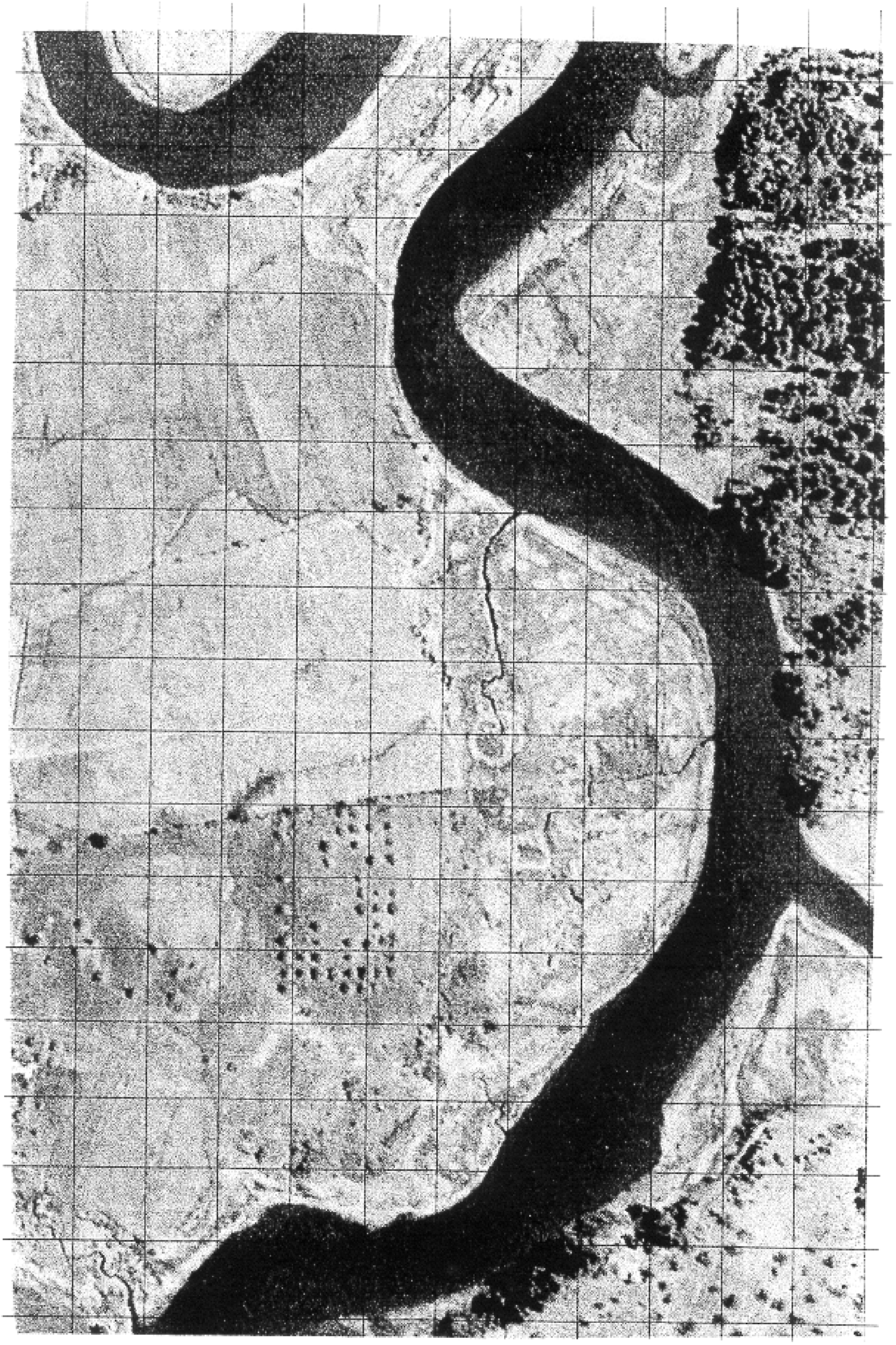

Figure 32. 1954 image of site 8 - Sewage Treatment Plant.

Site: Southern Oxbow 1995/1954 Top: (1995) Bottom: [1954]

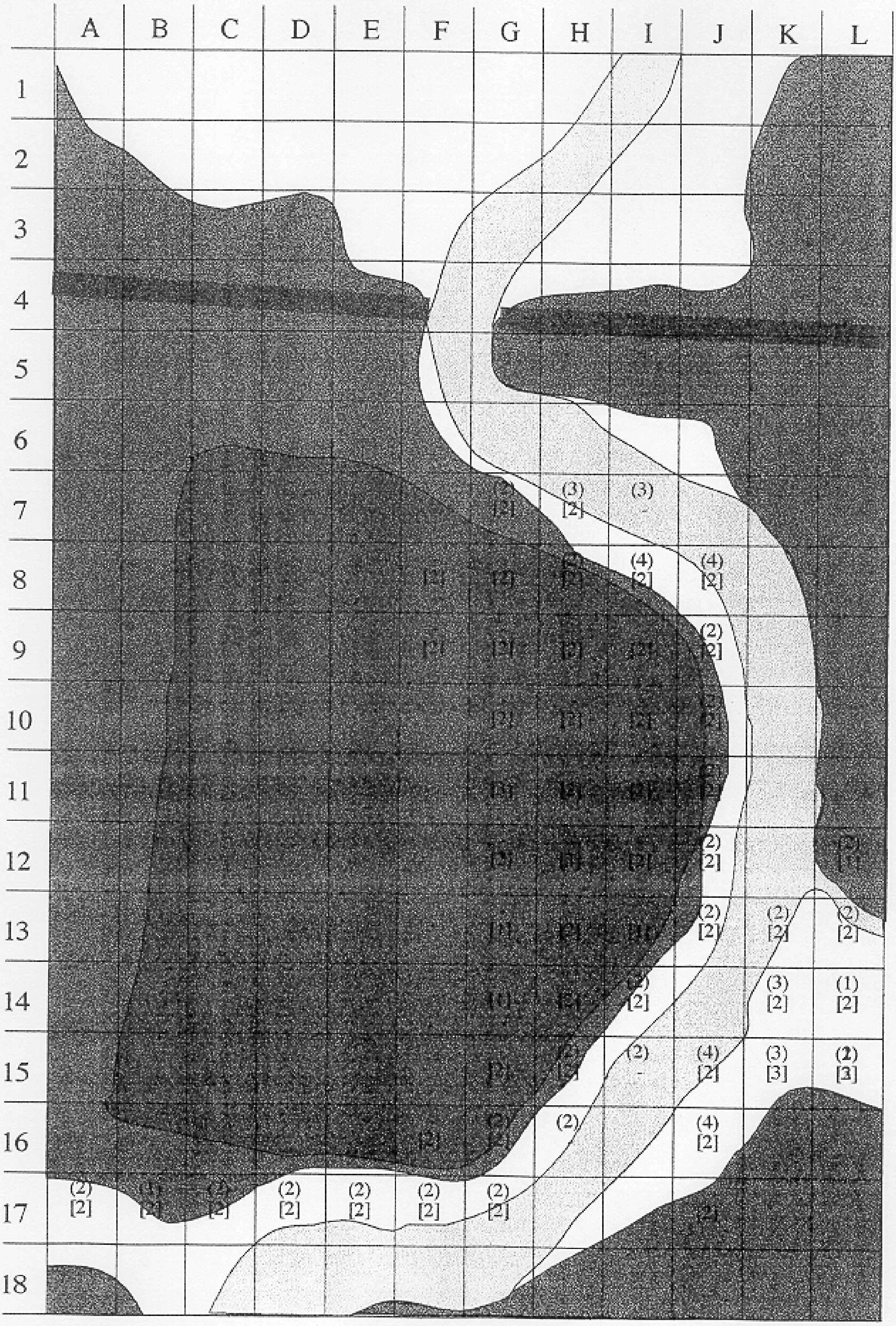

Figure 33. MCI analysis of site 8.

Site: Southern Oxbow

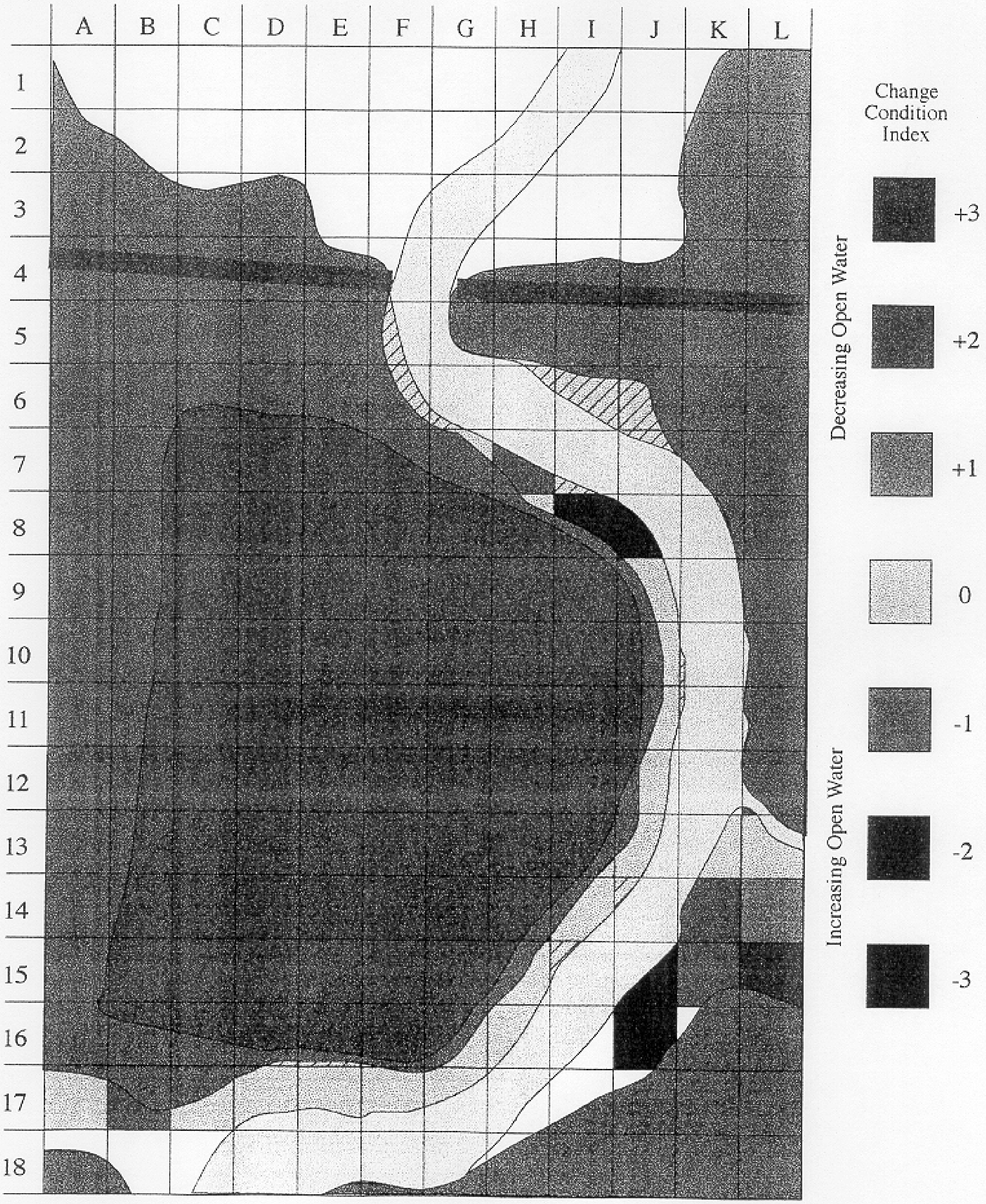

Figure 34. Trend analysis of site 8. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

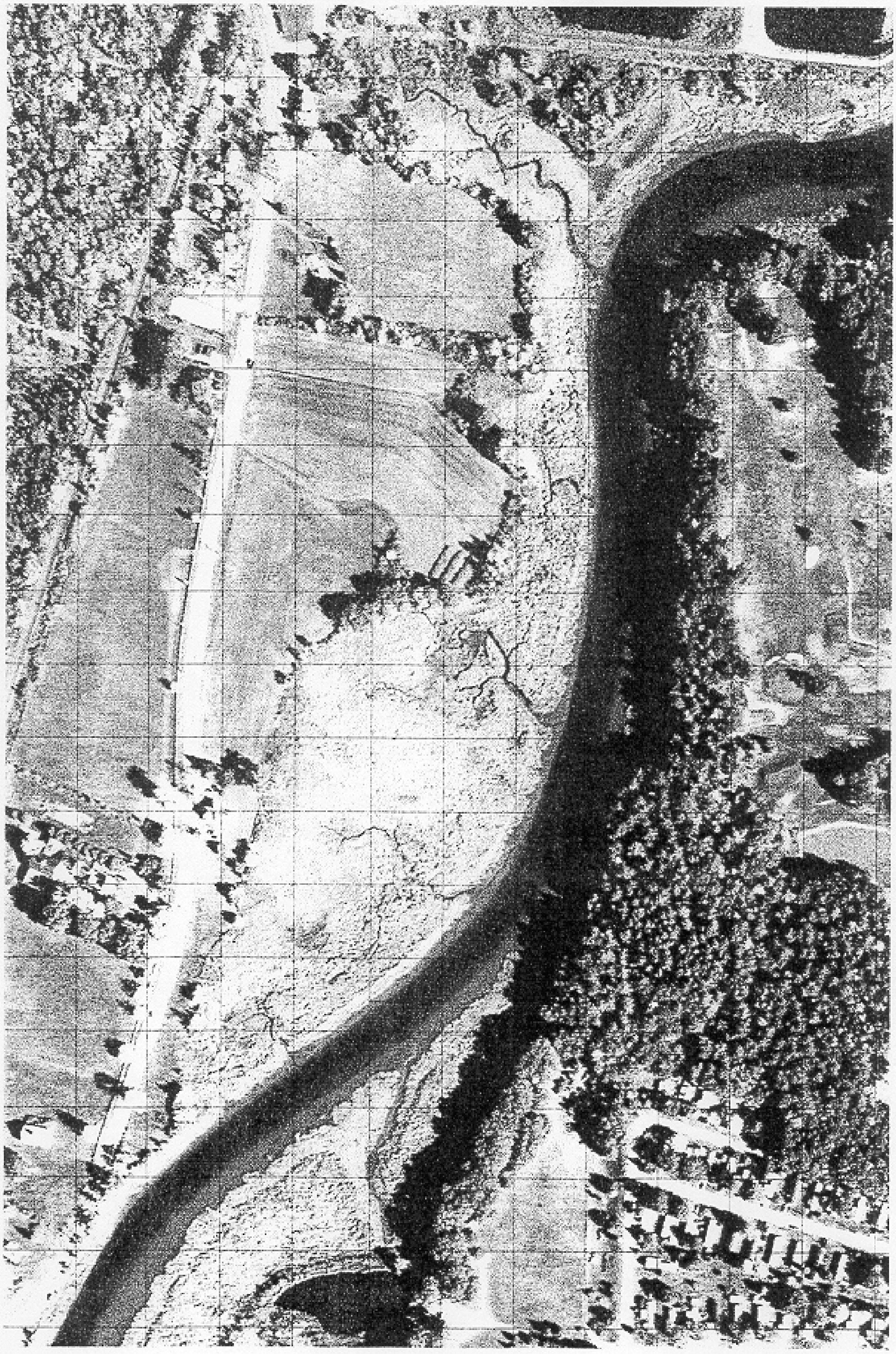

Figure 35. 1995 image of site 9 - Exeter North.

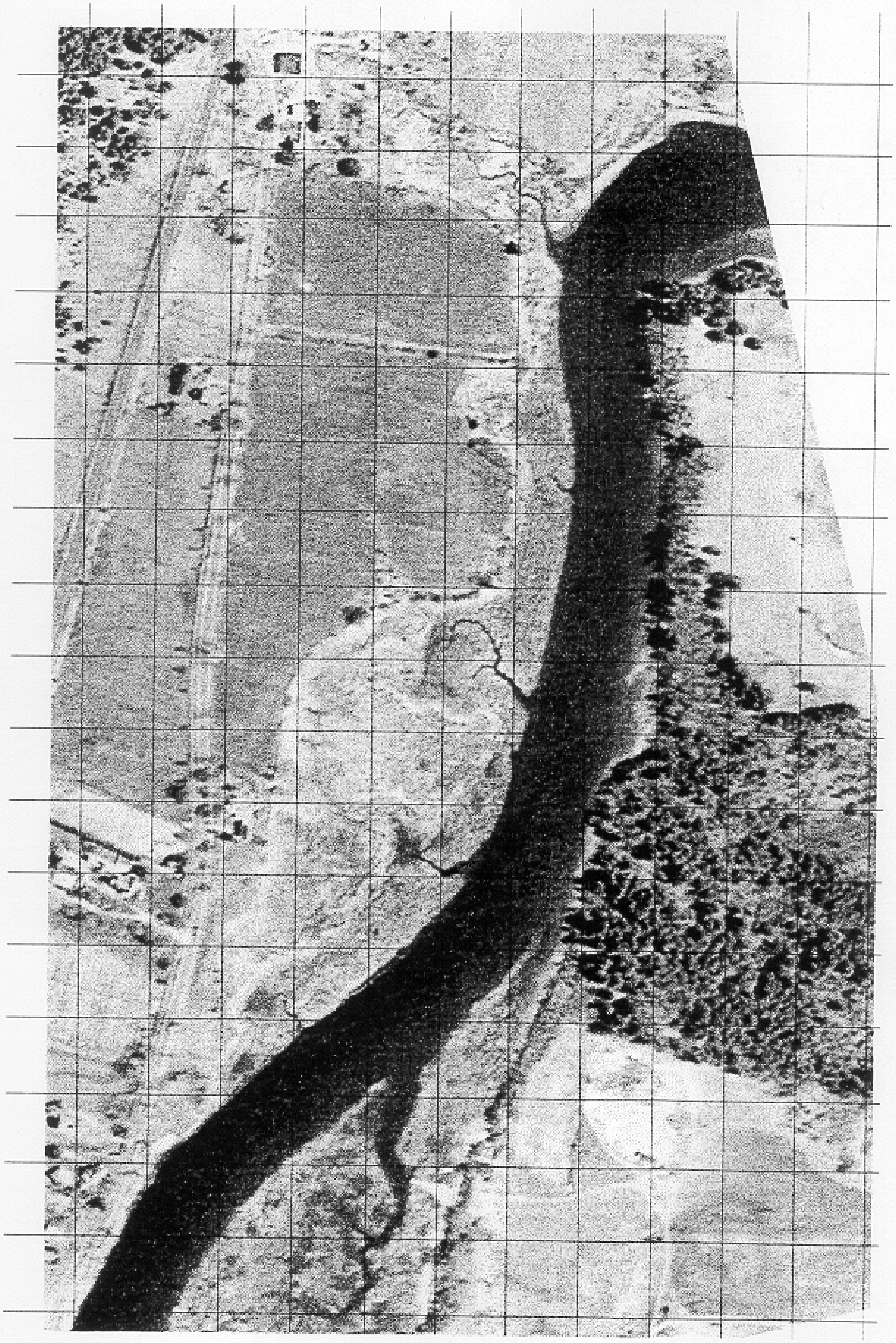

Figure 36. 1954 image of site 9 - Exeter North.

Site: Exeter North 1995/1954 Top:(1995) Bottom: [1954]

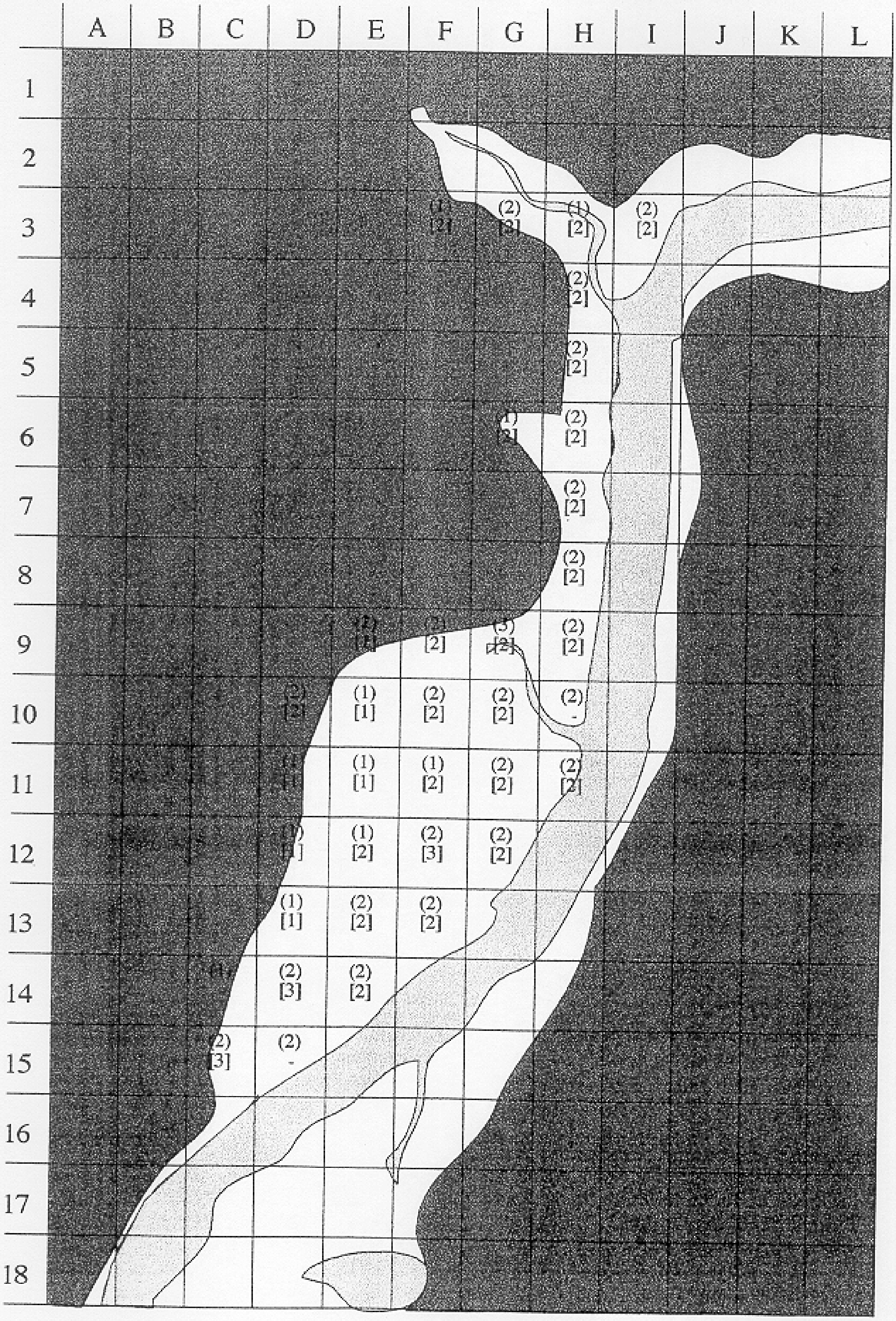

Figure 37. MCI analysis of site 9.

Site: Exeter North

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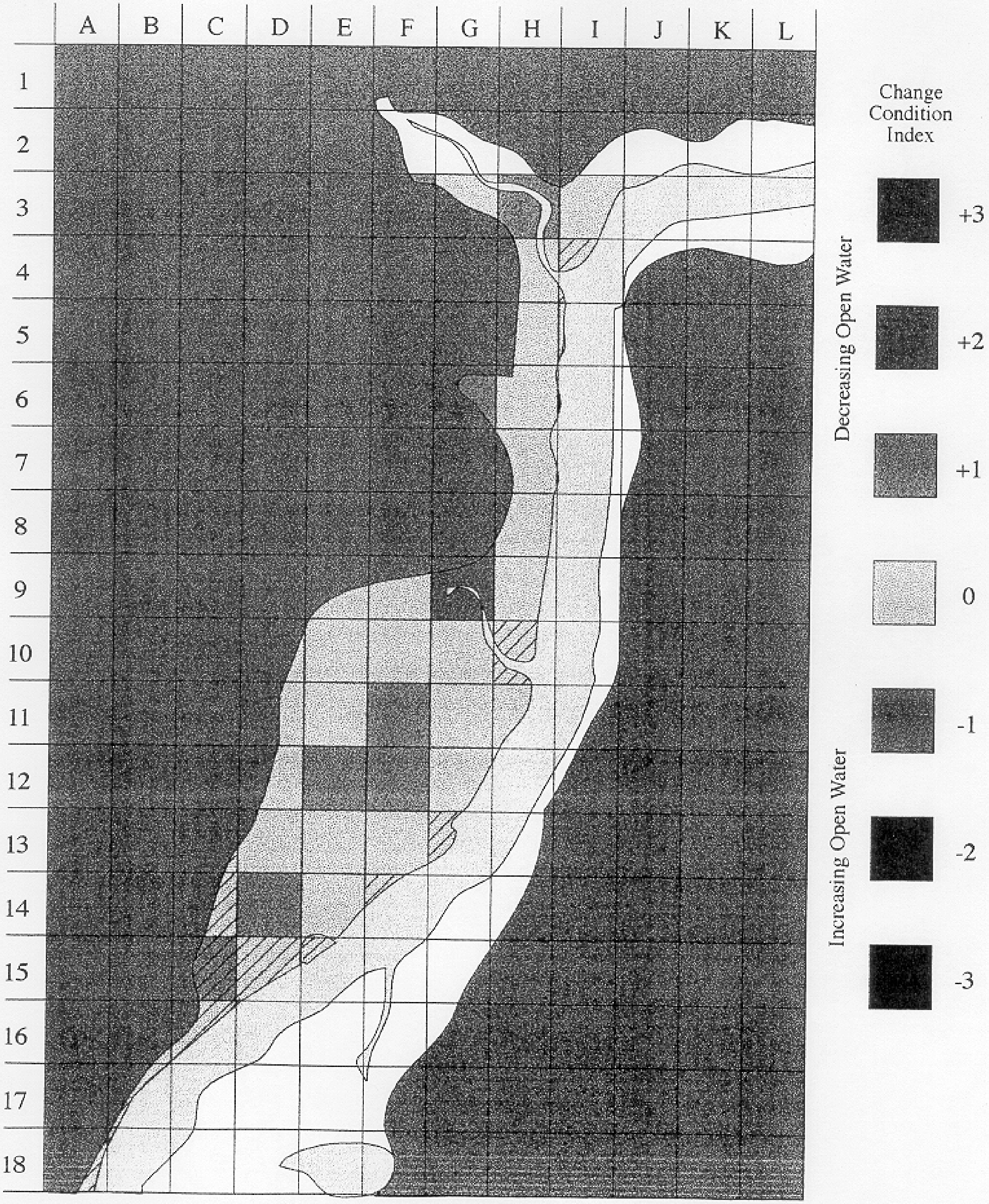


Figure 38. Trend analysis of site 9. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.

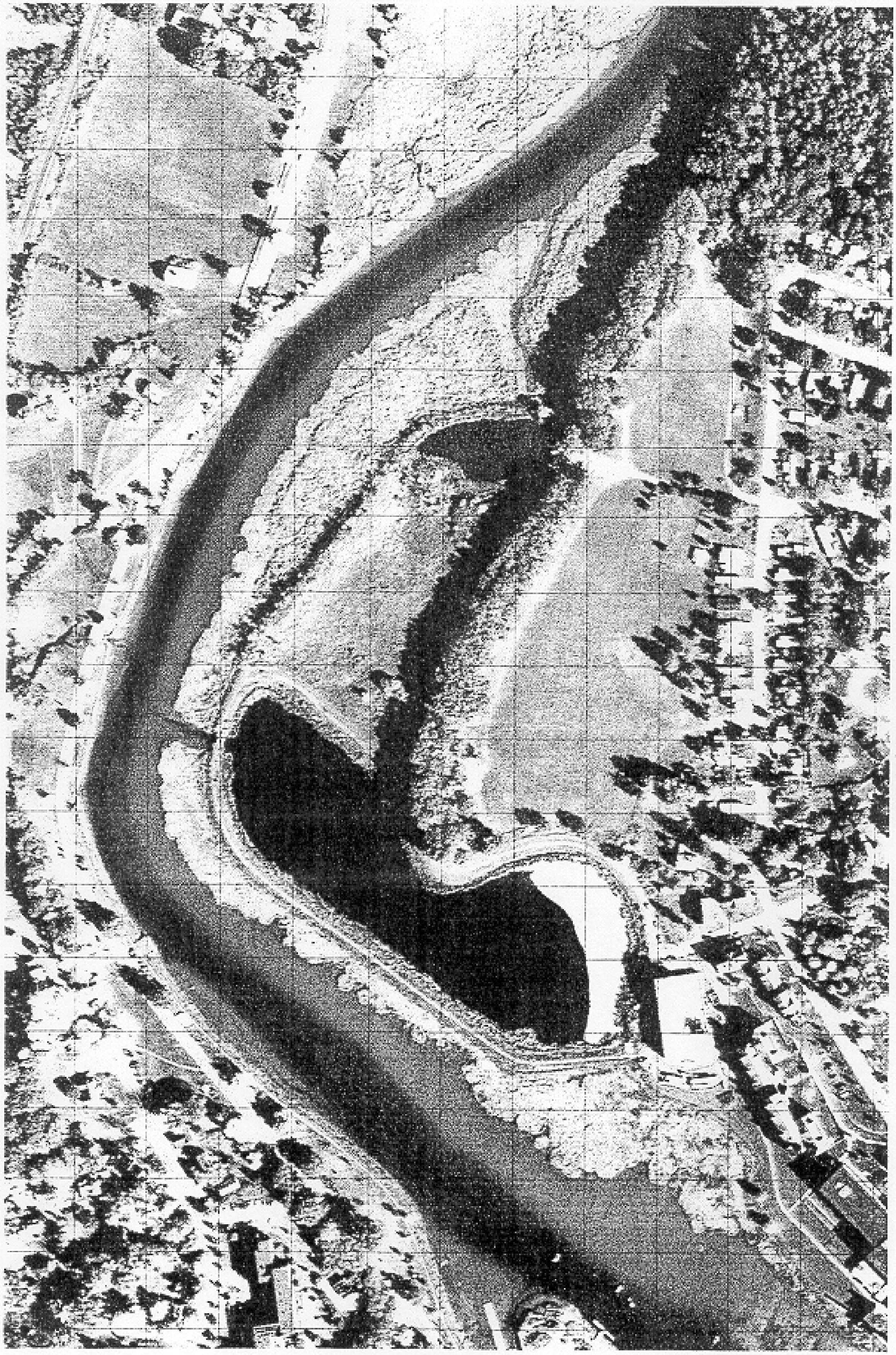


Figure 39. 1995 image of site 10 - Exeter Marsh.

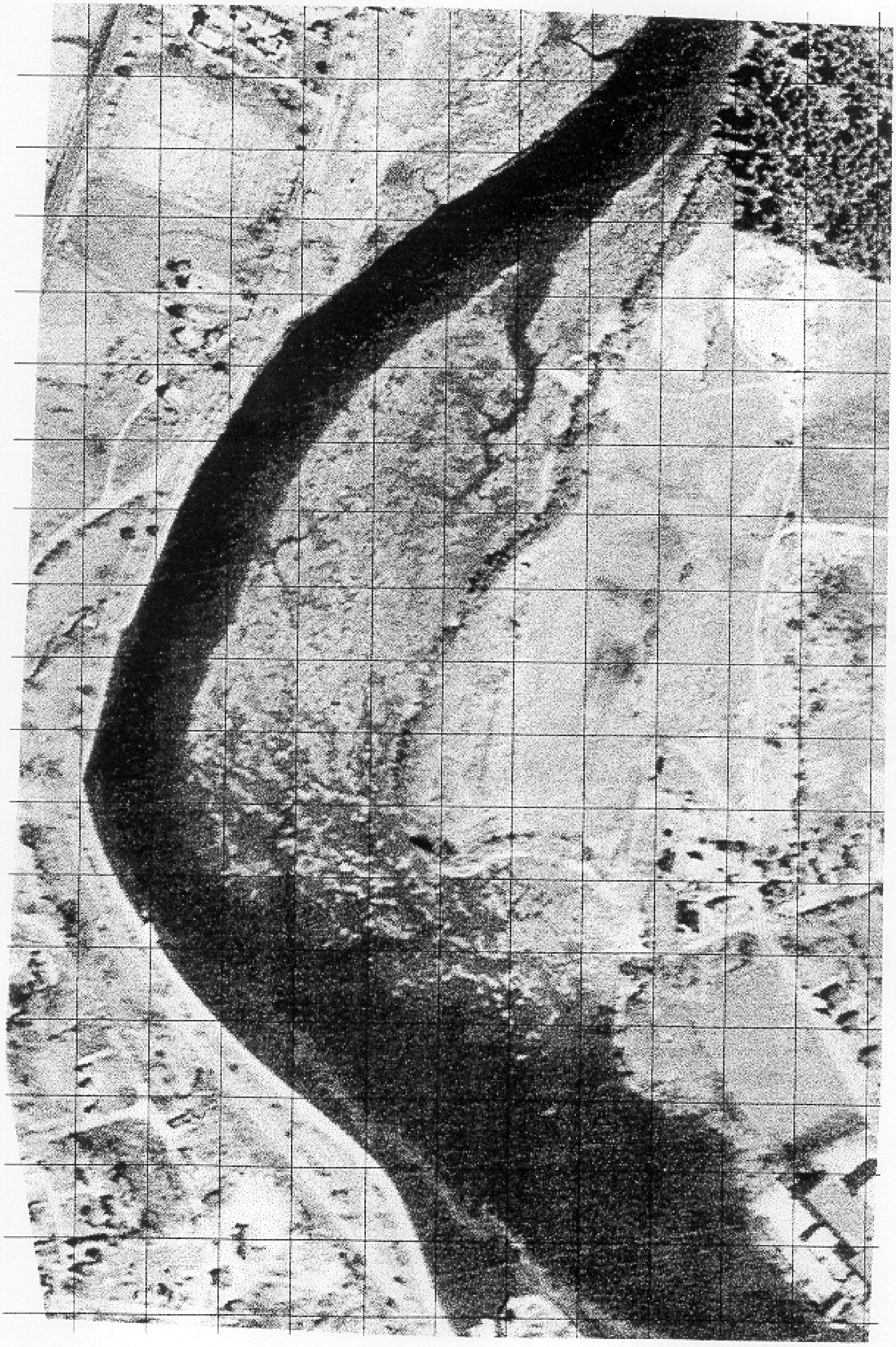


Figure 40. 1954 image of site 10 - Exeter Marsh.

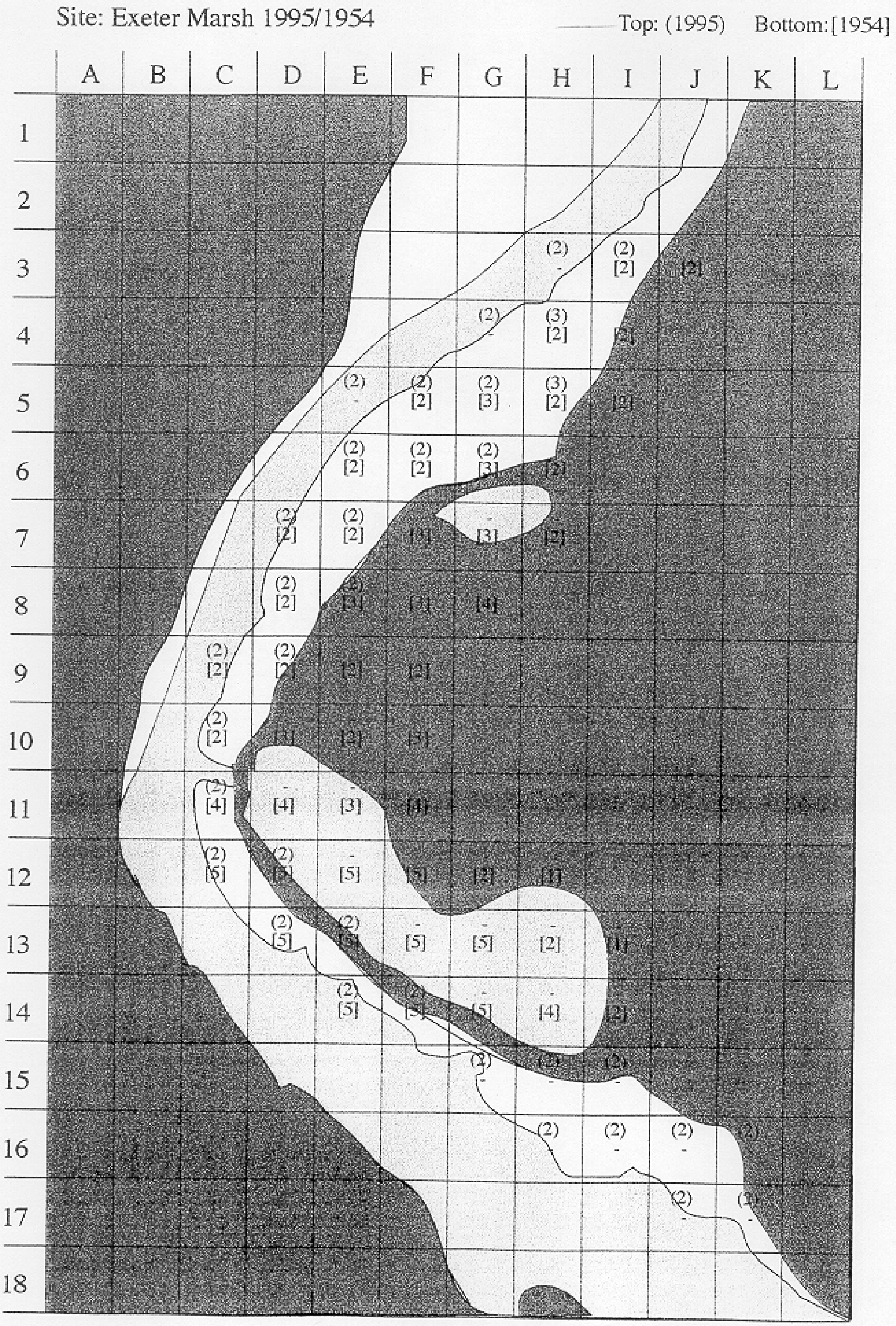
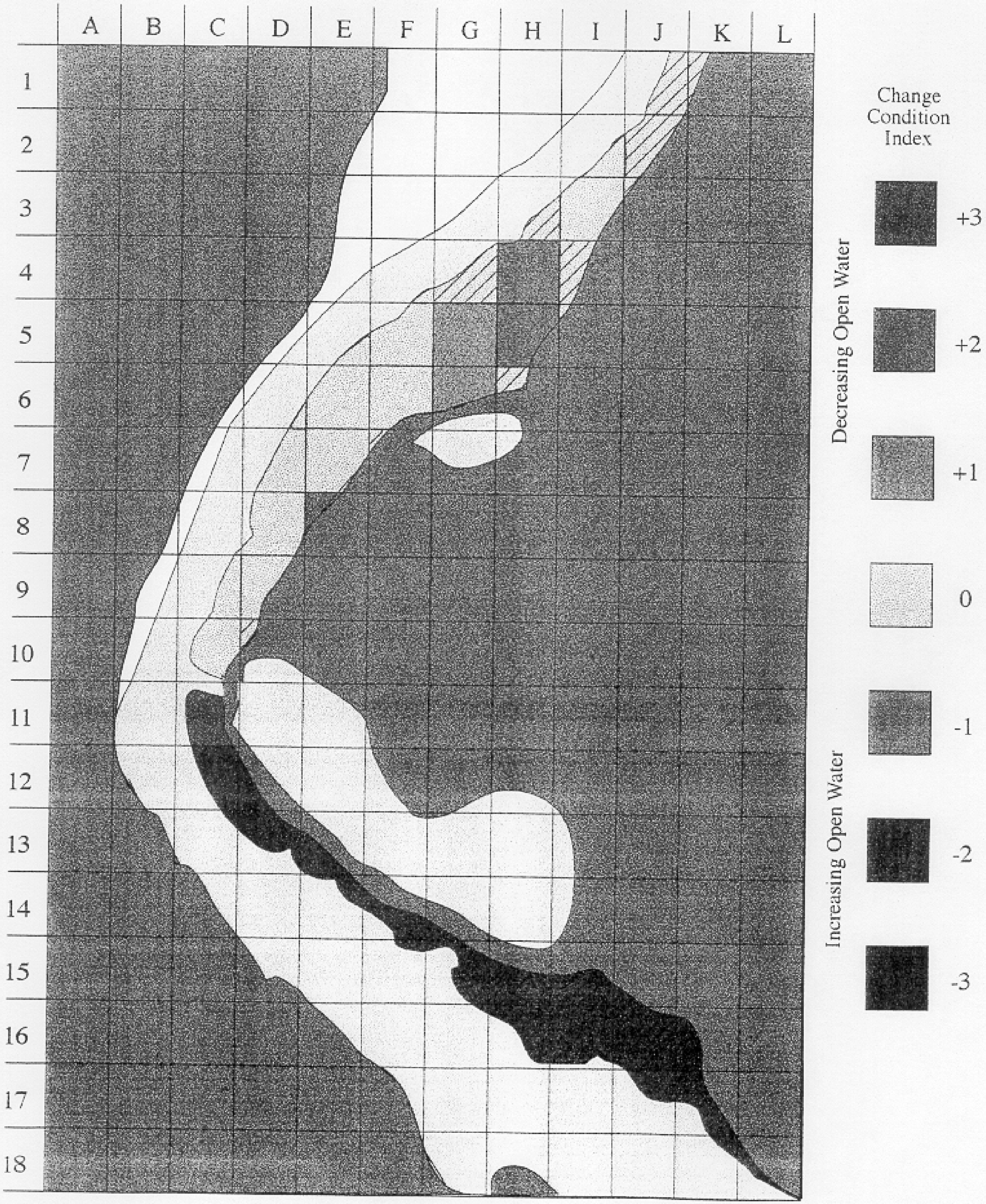


Figure 41. MCI analysis of site 10.



Site: Exeter Marsh

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Figure 42. Trend analysis of site 10. Diagonal lines indicate incomplete data for that section. Therefore, the interpretation of changes in that section is assessed from trends in the area.