COLLECTION AND INTERPRETATION OF COLOR INFRARED AND THERMAL INFRARED IMAGERY OF LANDFILL COVERS

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ABSTRACT

Earthen covers on a closed landfill are intended to prevent water from entering through the landfill cover and mixing with the wastes to produce methane and leachate. Landfill covers undergo changes in its local topography as waste volume changes in response to decomposition. The changes in local topography of the cover also changes drainage characteristics thereby causing some freely draining areas to impound water in depressions.

Required monitoring of closed landfills is currently performed by sampling and testing of downgradient wells. This method can detect groundwater pollution only after it has already occurred. A proactive method can indicate potential problems, such as locations where large amounts of rainwater are infiltrating through the cover.

Proactive monitoring of landfill covers by remote sensing methods is a promising supplement to passive monitoring by sampling wells. To test the method, color infrared photography and thermal infrared imagery were collected over three landfills in east central Illinois in June of 1991. Photography and post-sunset thermal infrared imagery were collected from fixed-wing airplane and helicopter platforms, respectively. The data were used to study the relationship of surface-drainage features to the infiltration of rainfall through landfill covers.

Interpretation of stereoscopic aerial photography is used to identify depressions. Thermal infrared imagery is used to classify depressions into freely-infiltrating or moisture-retaining depressions, identify stressed vegetation, and erosion. Thermal infrared imagery also is used to investigate the relationship of freely-infiltrating depressions to the venting of gas through landfill covers.

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Key Words: Aerial Photography, Color Infrared, Thermal Infrared, Landfill Covers, Depressions, Remote Sensing.

INTRODUCTION

Per capita waste generation in the United States has risen to 180 million tons per year and is projected to reach 216 million tons in the year 2000 (O'Leary and Walsh, 1991, p. 42-43). The increasing volumes generated have necessitated human society's attention in disposing of wastes.

Sanitary landfilling is the prevailing method employed in most industrialized countries ranging from 30% to 95% of the total solid waste generated by weight (Cossu, 1989, p. 5-9). A sanitary landfill is an excavation filled with wastes, covered daily by earth or geofabric, and finally closed by a thick covering of compacted earth. Landfilling is and has been used for ultimate disposal of some hazardous wastes in the United States and throughout the world (Frye, 1971; Schneider, 1975). Although considerable attention has focused on recycling of materials, the efficiency with which waste avoidance and recycling can reduce the amounts of solid waste is finite. Sanitary landfilling remains part of an integrated approach to solid waste management, and is needed for that portion of the waste stream that can not be recycled or incinerated.

The purpose of sanitary landfilling is to isolate wastes from human society and the ecosystem: water, soil and air. If water mixes with the wastes, the wastes decompose producing methane, leachate and a reduced volume of refuse (EMCON, 1980; Lu et al., 1985, Christensen and Kjeldsen, 1989, p. 29-32, Bogner, et al., 1990). An increase in the amount of water mixing with the wastes will necessarily cause an increase in the amount of leachate and methane generated by the decomposition. The production and release of methane into the atmosphere and leachate into groundwater can be detrimental to the surrounding ecosystem (Campbell, 1989).

Prevailing practice for evaluation of the effectiveness of a landfill in isolating wastes from the surrounding ecosystem is by means of monitoring wells, leachate collection systems, and personal field reconnaissance (Bagchi, 1989, Stohr, et al., 1990). Groundwater, sampled from monitoring wells, is analyzed for traces of chemicals found in leachates from the wastes. If waste products are detected, then leachate is known to have formed and discharged in the direction of the well, consequently remedial action must be taken to prevent further contamination of the groundwater. This passive monitoring by sampling and testing of wells detects pollution after it has occurred. It affords no warning prior to the need for remedial efforts to contain pollution.

Settlement of the landfill cover can initiate cracking, irregularities, and depressions in the cover (Stohr et al., 1990). Depressions are sources of undesired infiltration through landfill covers and can lead to groundwater pollution. Stohr, et al. (1987 and 1989) suggested that pollutants could enter monitoring wells downgradient of depressions in landfill covers.

Existing monitoring methods need to be modified in order to identify problems in sanitary and hazardous-waste landfill covers at a time when repairs can be made rather than when extensive remedial measures must be employed. The postclosure monitoring method should both incorporate existing passive monitoring methods, and supplement those methods with techniques that will alert landfill owners to changing conditions.

Prevention of leachate production depends in part upon the reduction of rainwater infiltration through the landfill cover. Most methods for estimating infiltration of rainwater through a cover do not consider irregularities such as depressions (Booth and Price, 1989). As a practical matter, irregularities and depressions that influence runoff are identified during field inspections.

Human recognition of depressions in landfill covers by field inspection a) is hampered by weeds, irregular topography, etc., b) is dependent upon recent climatological conditions, c) provides insufficient geographic documentation for independent review of data, and d) requires physical access to the site. Human observation is subjective because the man-made topography is complex and humans have insufficient stereoscopic perception to identify subtle or very large depressions on the ground. In independent field investigations at a hazardous-waste landfill, a field observer found only 6 depressions whereas 28 depressions were found by aerial photointerpretation (Stohr, et al., 1987). In addition, active settlement is continuous and difficult to perceive if not measured by instrumentation.

Some of the depressions found using aerial photointerpretation were field checked for surface drainage and infiltration characteristics, and then distinguished according to their thermal characteristics. Two categories of depressions were classified according to thermal characteristics using post-sunset, ground-based thermal infrared (IR) imagery: moisture-retaining and freely-infiltrating.
Moisture-retaining depressions mainly lose water by evapotranspiration and so appeared relatively cooler than surrounding ground. Freely-draining depressions mainly lose water by flow through the cover and so appeared slightly warmer than surrounding ground (Stohr, et al., 1987).

OBJECTIVES

The objectives of the study are:

- Determine the types of landfill cover features that can be interpreted from aerial photography;
- Identify depressions on landfill covers using stereoscopic aerial photointerpretation; and
- Classify depressions according to their thermal properties.

METHODS AND MATERIALS

Nine-inch, 1:3300-scale, color-infrared (CIR) aerial photography and thermal infrared imagery were collected on June 18, 1991 for a closed landfill in east central Illinois. Post-sunset thermal IR imagery was collected using two instruments, a Daedelus line scanner and a FLIR, Inc. frame scanner. The two thermal IR instruments gathered imagery on separate aircraft.

Thermal IR imagery was flown after sunset in order to avoid problems with ground fog which can develop near sunrise, and problems with dew that develops a few hours after sunset.

Ground control points from a previous survey were recovered and marked in the field. Additional points were added by aerotriangulation using 1:7600-scale, black and white aerial photography recorded on March 30, 1988.
The use of a stereoplotter permitted the addition of control points for registration of single color-infrared photographs. Registration of individual photos was performed in lieu of rectification of the photos because the amount of tip could not be compensated by the stereoplotter. In that the CIR photos have a scale larger than the older photography, registration was found to be within a few feet of the control points.

Photogrammetric aerotriangulation was performed with a modified Zeiss Stereotop stereoplotter, a custom made pantograph, a modified GTCO digitizing board and ARC/ INFO, geographic information system (GIS) software.

External temperature calibration allows inference of "absolute" temperature/thermal emittance for changes in moisture associated with depressions on the landfill cover. Nearby water bodies and water-filled wading pools that we set out on the site were used to record water temperature for external calibration. Temperatures were recorded using a thermometer and a hand-held radiometer.

Aerial photointerpretation was performed using both folding and mirror stereoscopes. A parallax bar was used to measure the relative height of terrain.

LANDFORMS ON LANDFILL COVERS

A landfill cover is a constructed landform that has features not found in nature. Landfill covers are constructed of compacted fill and topsoil. Although the intention is to construct a near-natural setting, the placement of organic material and subsoil may be unnatural and uneven. Segregation and uneven distribution of fill will influence the density and vigor of plant growth. Sewage sludge and compost may be applied unevenly promotes discontinuous plant growth on the landfill cover.

Interpretation of the disturbed ground of the landfill cover on black and white photography is complicated by misleading visual cues (tone, texture, optical slant and impression of a closed contour). To an aerial photointerpreter dark and light tones may appear out of place or unrelated to physical features and vegetation. These complications are made more difficult by the subtle detail sought on large scale black and white aerial photography.

The relationship of the man-induced features to surface drainage is important to the proper mainte nance of the cover for its intended purpose i.e., to reduce infiltration. Features found on landfill covers include:

- depressions
- drainage obstructions (erosion control dikes)
- landslides
- seeps and springs
- stressed or diseased vegetation
- erosion gullies and rills
- trails and ruts
- drainage boundaries

Depressions are low, undrained areas of a landfill cover. Because depressions have no surface outlet for drainage, moisture is dispersed by evapotranspiration or infiltration. Internal drainage or free infiltration is undesirable because water drains through the cover where it can mix with wastes to form leachate.

Irregularities in a constructed surface may be caused by grading. Such irregularities become potential problems when they impede drainage. The final design and grading of a landfill cover includes features such as erosion control dikes that work at "cross purposes" i.e., the features reduce erosion but increase infiltration through the cover. Reduction of erosion would spare maintenance costs at the expense of increased leachate production.

IDENTIFICATION AND CLASSIFICATION OF DEPRESSIONS

Depressions are commonly recognized by topographic relief and associated visual cues: change in tone, optical slant, change in land cover, and shadowing. The combination of unevenly distributed vegetation on segregated light and dark soils poses problems for discerning subtle characteristics of depressions on a well graded and maintained landfill cover.

Interpretation of depressions can be improved by properly orienting the stereopair and by using a parallax bar. A stereopair is properly oriented for viewing when the principal points and their conjugates on both photographs are aligned. A relative orientation, visually manipulating the photographs to achieve stereoscopic viewing, can cause misinterpretation of the man-made surface with its associated unnatural visual cues because the interpreter does not recognize that each eye is looking at different features.

A parallax bar is necessary to determine the relative height of a landscape element, rather than depending upon interpretation of visual cues, which may be inaccurately perceived to be similar to natural landforms. Clumps of plants pose problems in closing contours.

Distinguishing topographically low areas that collect runoff from vegetation is important to the identification of depressions. Vegetation clumps and moist soils both appear dark on black and white photography, causing uncertainty in distinguishing vegetation reflectance from the darkening of the soil. However on color IR photography, vegetation appears red or pink whereas moist soils appear dark blue or black. Color infrared photography is more useful than black and white in distinguishing soils and vegetation.

Vegetation density (biomass) as perceived on the ground may have a different appearance on color IR photography. Grassy vegetation growing up to one meter high appears to be lush in the field, but may have only a pink or pale red color on the color IR photography. The pink color ambiguously indicates either vegetation stress, low leaf area, or lack of sufficient biomass to generate the familiar magenta color associated with healthy foliage in humid regions.

Topographic maps having a 2-foot contour interval are a commonly used method for identifying minor landscape features. Figure 1 shows a portion of a 2-foot contour topographic map of a closed landfill. There are no closed contours shown on the map, however depressions can be found by aerial photointerpretation and field reconnaissance.

Figure 2 shows three depressions on a landfill cover. The depressions were found by stereoscopic interpretation of color infrared aerial photography. The depressions were recognized in the field by their topographic relief.

Classification of the depressions can be made on the basis of thermal characteristics ie., whether the depression is warm (freely-infiltrating) or cool (moisture-retaining). Figure 3 is a thermal infrared image showing a portion of the area depicted in Figure 2. Two of the depressions, A and B, appear dark-toned and relatively cool in the post-sunset aerial thermography suggesting that they are retaining moisture near the surface available for evapotranspiration. One of the depressions, C, shows no contrast with the surrounding light-toned, relatively warmer well-drained cover suggesting that moisture is freely-infiltrating through the cover.

There are two types of moisture-retaining depressions observed in Figures 2 and 3. The concentric appearance of an old, moisture-retaining depression, A, is indicative of a long established depression. Cattails, a type of hydrophytic vegetation, are found in the depression (Figure 4).

The presence of cool, moisture-retaining depressions and warm, freely-infiltrating depressions is consistent with previous work by Stohr, et al. (1987). The previous study was performed in summer, whereas this imagery was gathered in spring indicating that the post-sunset thermal-moisture relationship does not vary between those two seasons.

CONCLUSIONS

Initial results show that:

- color infrared imagery is more useful for distinguishing vegetation from dark, moist soils than black and white photography,
- aerial photointerpretation can be used to identify depressions not shown on 2-foot contour interval maps,
- vegetation density differs on landfills of varying ages,
- the number and detail of depressions identified in landfill covers varies with scale and type of photography,
- aerial thermal IR imagery can be substituted for ground-based thermal IR surveys of moisture characteristics of depressions,
- thermal characteristics of moisture-retaining and freely-infiltrating depressions appear to be consistent on several landfills, and in both spring and summer seasons.

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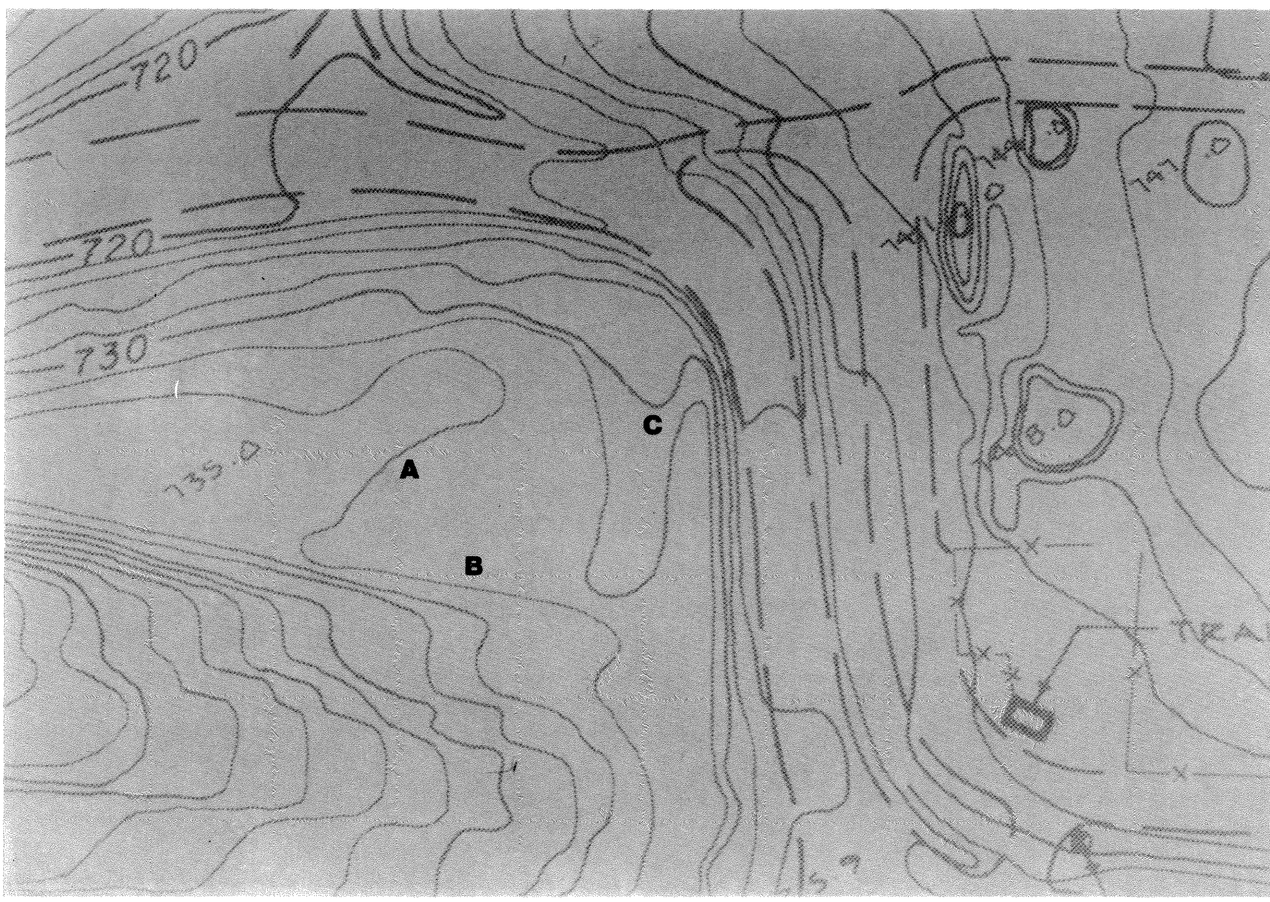

Figure 1. Portion of a 2-foot contour interval topographic map of a landfill in east central Illinois. Three depressions, A, B, and C, found by photointerpretation are shown on the map.

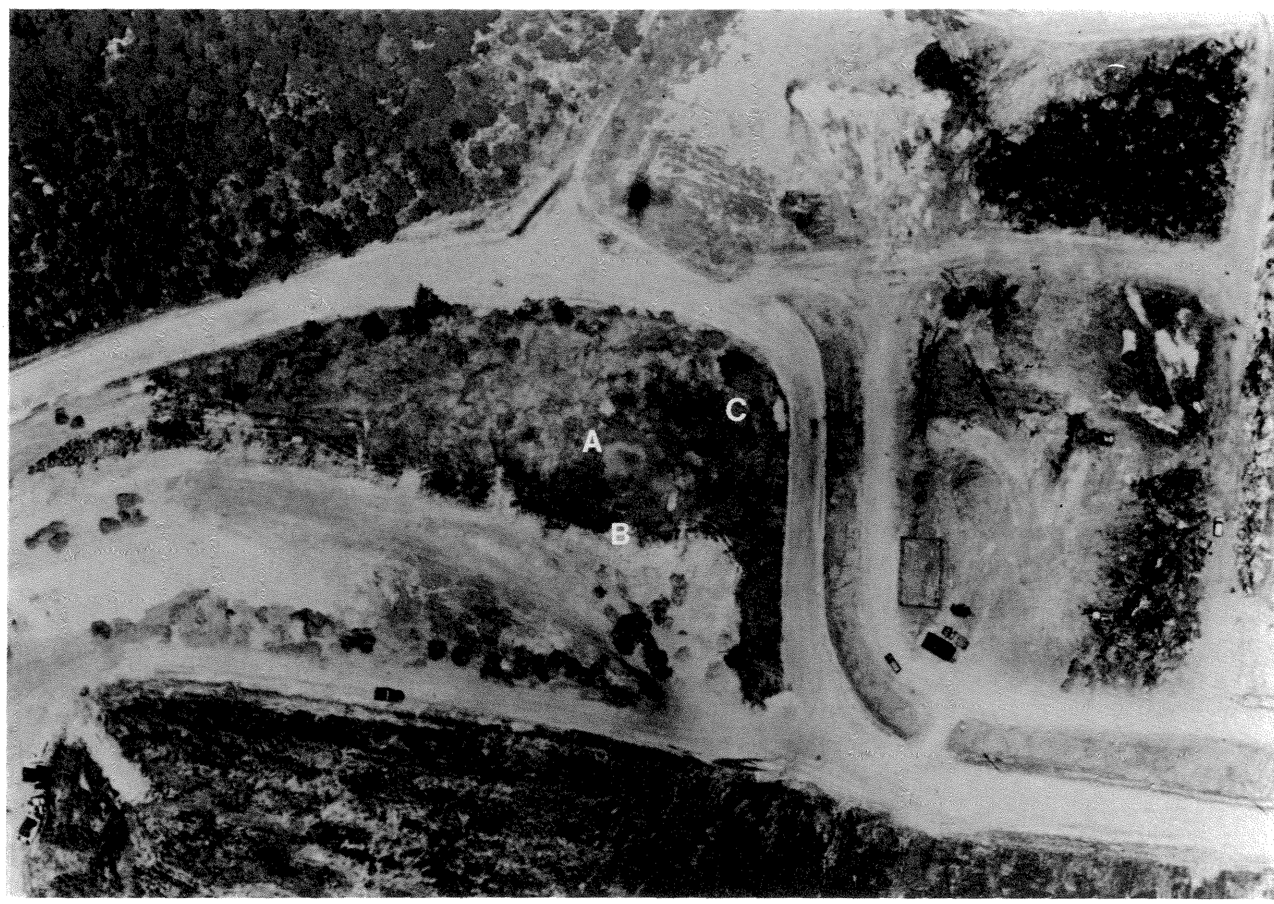

Figure 2. A black and white copy of a color infrared aerial photograph of a closed landfill in east central Illinois, USA. The photo recorded on 18 June 1991, shows 3 depressions, A, B, and C, on the landfill cover found by stereoscopic photointerpretation.

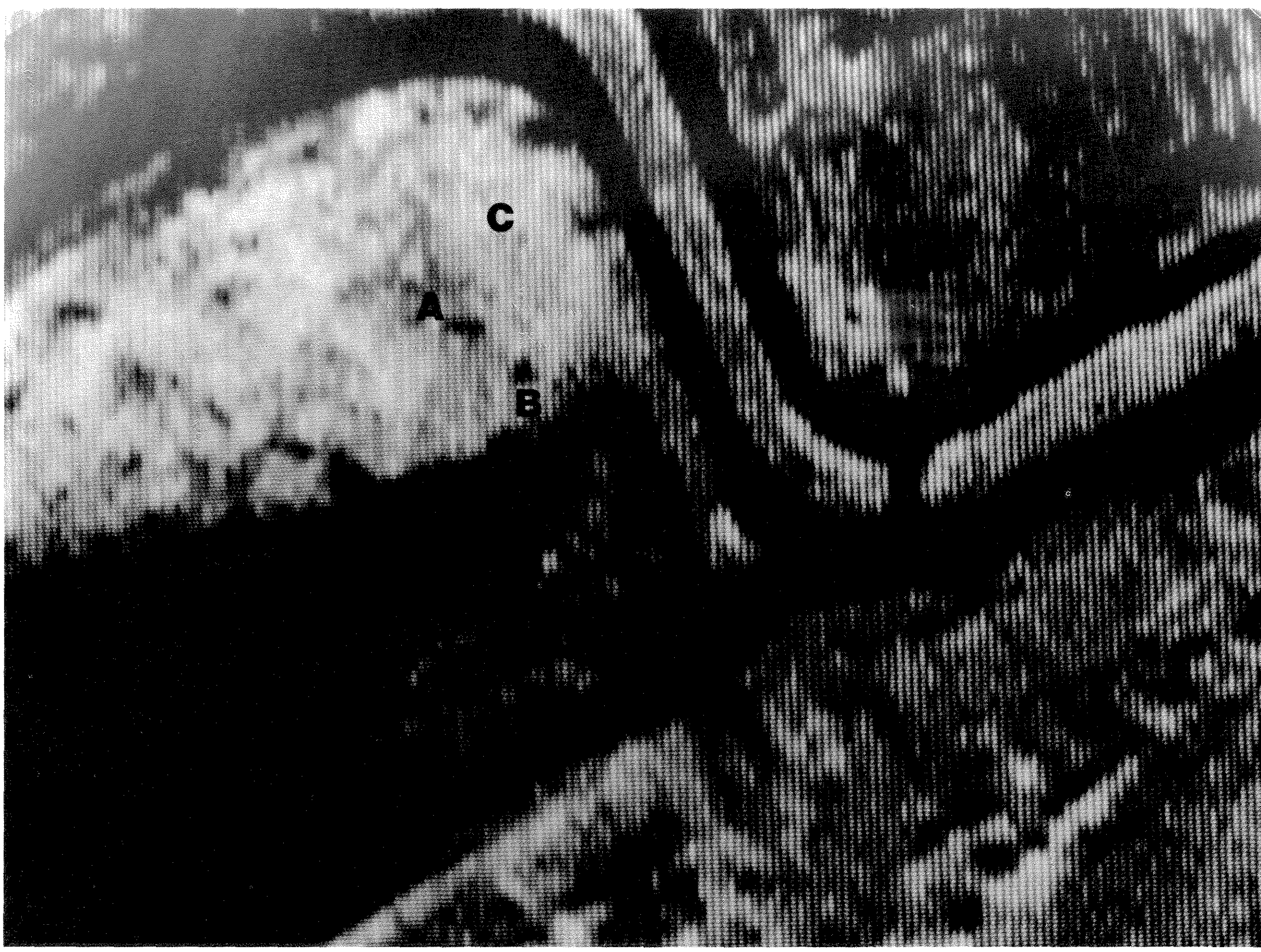

Figure 3. Thermal infrared imagery showing a portion of the landfill area shown in Figure 2. Two of the depressions appear dark-toned, relatively cool in the post-sunset aerial thermography, whereas one of the depressions shows no contrast with the surrounding light-toned, relatively warmer well-drained cover.

Figure 4. Cattails, a type of hydrophytic vegetation, are found in the concentric depression, A, shown in Figures 1, 2, and 3.