Vermont Stream Geomorphic Assessment

Appendix D

Delineating Watershed Drainage Area

Topographic Maps And Aerial Photography

Vermont Agency of Natural Resources
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Delineating Watershed Area

Watershed areas can be drawn with map and pencil or with computer mapping tools; however, it is highly recommended that you use paper topographic maps to first draw watershed areas and complete reach numbering. Digitizing on-screen from scratch can be inefficient, as the user must switch back and forth between a small scale in order to see topographic features and a larger scale to see drainage patterns. It is also extremely valuable to have the paper maps as a backup and for educational display.

Materials needed

- USGS 1:24,000 topographic maps
- tape
- pencil and eraser

Procedure

1. Tape together a composite of the all the topographic maps on which the watershed is located. To determine which maps these are, you will need to have a general sense of where the mainstem river or stream flows and which larger tributaries flow into it. Each USGS topographic map covers about 53 square miles of land area.

2. On the map, mark the watershed outlet, which is the most downstream end of the stream, river, lake, or reach you are assessing. Examine the map to identify all land area that directs water to the watershed outlet. Look for the blue lines, which indicate surface water, that flow to the watershed outlet, and visually follow these blue lines upstream until they end. All of these blue lines that drain to the watershed outlet make up the drainage network (Figure D.1). From the most upstream ends of the blue lines, follow the contour lines uphill until reaching the ridge tops of the drainage divide. The contour lines along a stream make a V with the point of the V facing uphill, and ridges make a U (sometimes V-shaped) with the bottom of the U facing downhill.

3. Draw the watershed boundary by connecting all the ridge tops and highpoints from which the land slopes down to the river (or lake) and eventually to the watershed outlet. Watershed boundary lines are drawn at right angles to the contour lines on the topographic maps'. Start at the watershed outlet and work upstream, drawing the watershed boundaries on one side of the watershed; and continue to follow the ridges around until you come back to the watershed outlet on the opposite side of the watershed. The watershed boundary line you draw should encircle the entire drainage network of the watershed. Sometimes it is easier to visualize watershed boundaries by first looking for the tops of hills and mountains and "connecting the dots", ridge top to ridge top, around the waterbody.

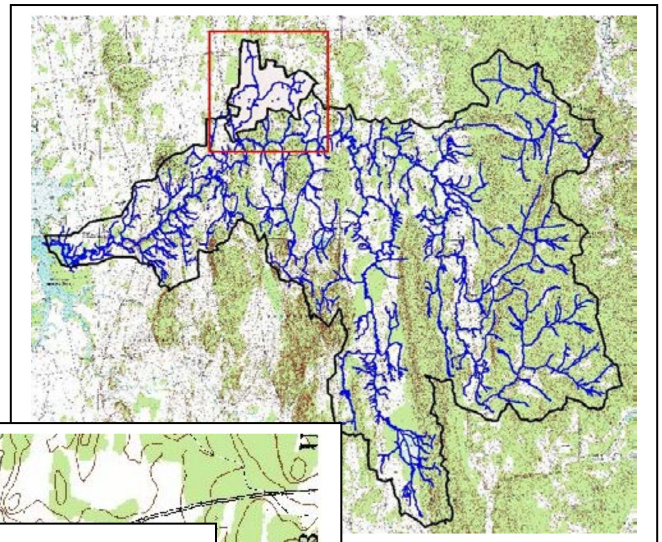
Notes

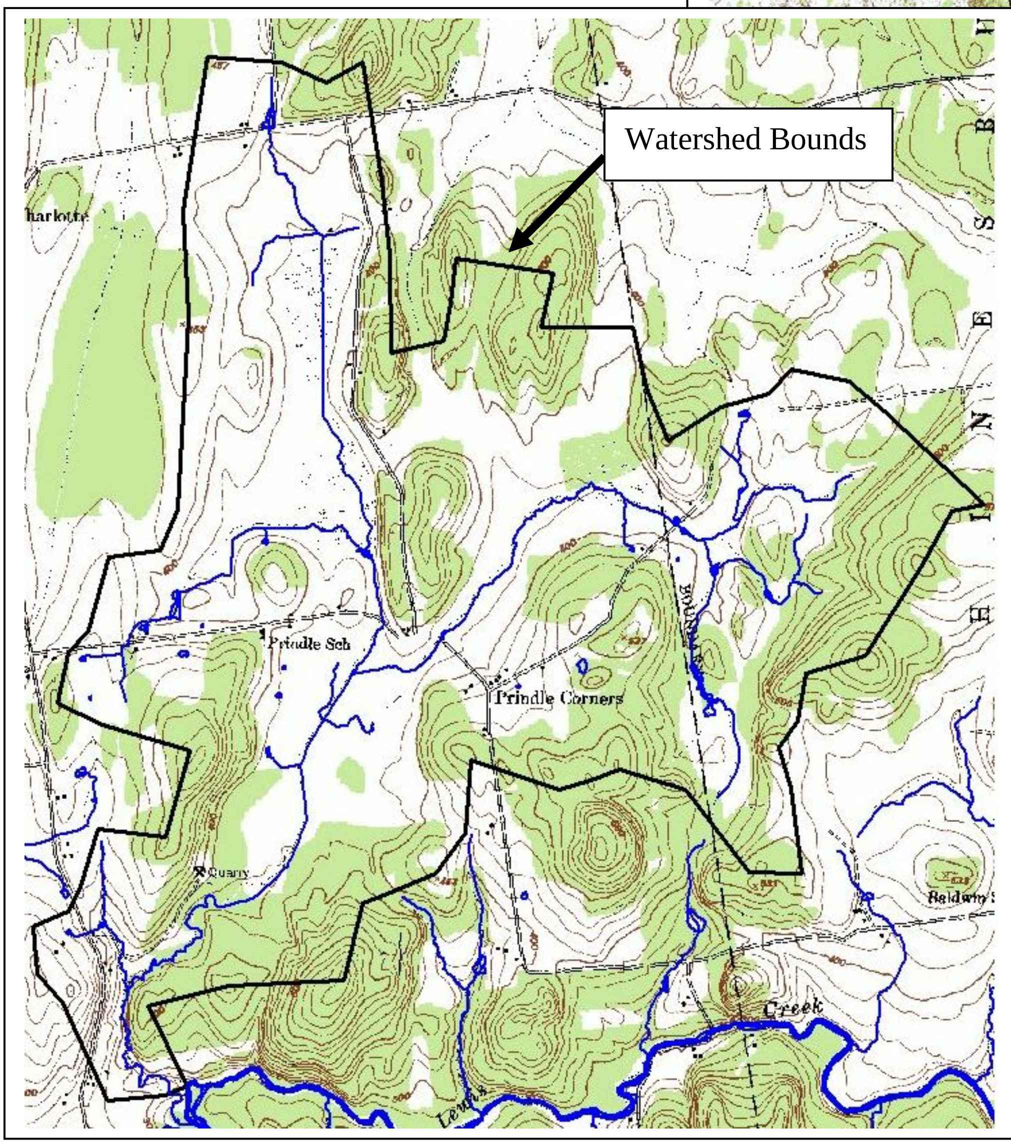
- If a wetland sits on a drainage divide between two watersheds, divide the wetland in half with the watershed boundary line. It is likely that the wetland drains in both directions, into the watershed you are delineating and into the adjacent watershed.

- Be careful in urban areas because stormwater drainage and water supply systems can sometimes significantly change the locations of drainage divides. Contact the city engineer for information.

- Check your work by examining the contour lines within the watershed boundaries to make sure that there are no points, other than the outlet, where water flowing off the land could cross the watershed boundary lines and leave the watershed.

Figure D.1 Below, the watershed area drawn for a tributary stream. Inset on right shows the location of the tributary watershed within the larger mainstem watershed. The drainage network is shown in blue.





Topographic Maps and Aerial Photography

Reading a Topographic Map

Becoming familiar with the topographic map is essential for understanding a watershed. Two features used frequently are the scale, which can be read at the bottom of the map, and the contour lines. The scale relates the distance between two points on the map ad the actual distance. The United States Geological Survey (USGS) produces several series of topographic maps with different scales. The two most common are the 1:24,000 and the 1:100,000 series. On a 1:24,000 map, a distance of one unit on the map equals 24,000 units in the field.; For example, 1 (map) inch = 24,000 (field) inches or 2000 feet. Contour lines are lines of equal elevation, typically 20 feet or 6 meters apart on the 1:24,000 series map. Every fifth contour line is darkened and this helps to make reading the map easier. Since contour lines are lines of equal elevation, when they are closer together, it indicates steeper terrain, and when they are further apart, the land is flatter. Many stream features such as channel slope, valley slope, sinuosity, valley width, basin slope, location of alluvial fans, drainage area etc. can be read from a topographic map.

The list below includes some of the most common features that you will see when reading a topographic map.

Note that while some valleys on the map show streams flowing through them, others do not. This does not mean that there is no stream there, it means that a perennial stream was too small to detect when the map was made or the stream is ephemeral (not flowing all the time). The dotted blue lines indicate larger ephemeral streams, solid blue lines indicate perennial streams.

Guide to main features on a topographic map

Hill summit: closed round circle
Depression: closed round circle with small lines pointing to the center of the circle.
Valley: V shaped contours with the point of the V facing UPHILL.
Ridge: U or V shaped contours with the point of the U facing DOWNHILL.
Steep terrain: contour lines close together
Flat terrain: contour lines farther apart
Slope breaks: These are areas where alluvial fans, or multiple channels may occur.

Using Aerial Photographs and Orthophotos

Introduction

Aerial photograph interpretation is an easy and low-cost way to view a large area of land in its entirety. With the right photos and a small amount of training, aerial photographs can reveal a tremendous amount of information about rivers and watersheds.

As the subject is a broad one, this section can only provide a brief introduction. Anyone seriously interested in photo interpretation should refer to Avery and Berlin (1992) and Philipson (1997).

Aerial photos can be divided into two broad categories: Vertical photos are taken with a camera which is pointing approximately straight down and oblique photos are taken at some angle other than vertical. The typical photo taken by pointing a handheld camera out an airplane window is an oblique photo. Oblique photos can themselves be divided into two categories: low obliques, which do not show the horizon, and high obliques, which are so slanted from vertical that they include the horizon. Although these photos can be very helpful for evaluating a stream corridor it is not usually practical to make any actual measurements off of oblique photos.

Vertical aerial photos are usually taken with a special mapping camera which is mounted in the belly of an airplane. The actual film is about 10 inches wide and the lenses vary in focal length from 6 to 12 inches. A gyroscopically stabilized mounting keeps the camera vertical as the plane flies along and a special forward motion compensation device may be used to reduce blurring caused by the motion of the plane during the time the shutter is opening and closing.

A series of aerial photos taken as the plane is flying along on a constant heading is called a flight line. Ideally the photos line up in an exactly straight line. In practice, the photos may be somewhat canted to the line of flight or else the line may drift sideways relative to the intended line of flight. Flight lines are most often oriented north-south, although small projects may use other orientations so as to cover a project area with the least amount of reversals of the plane. The photos in a flight line are usually taken so as to overlap by about 60 percent. Photos in adjacent flight lines typically overlap by 25 to 30 percent. The overlap along flight lines allows stereoscopic viewing of adjacent pairs of photos. This is the single most important technique to master in order to interpret aerial photos.

The Geometry of Aerial Photos

Although aerial photos are often thought of as being maps, this is not really correct. Simple maps can be thought of as what are known as orthographic projections. In an orthographic projection all features are located in their correct horizontal positions and are depicted as though they are being viewed from directly overhead. Angles and distances can be easily measured on such maps. Aerial photos, by contrast, are central projections. In a central projection all features are viewed from a single central point that is a finite distance above the scene. This results in the images of most objects being shifted from their proper map positions, a phenomenon known as radial displacement or image displacement. Most of this displacement is caused by the shifting of images radially towards or away from the center of the photo depending on whether the features are lower or higher than the elevation of the land at the center of the photo.

Other sources of distortion in aerial photos are camera tilt and distortion due to the camera lens itself, both of which are usually quite minor. Lens distortion is usually greatest at the edges of the photo, so its good practice to avoid working at the edges of the photos.

Scale of Aerial Photos

The scale can vary significantly over a single aerial photo. First, the hills are closer to the camera than the valleys and thus the hills are shown at a larger scale while the valleys appear at a smaller scale. Second, the distance from the camera to the edge of the scene is larger than the distance from the camera to the center of the scene. In hilly terrain scale variations within a single photo can sometimes exceed 5%.

The scale also varies from one photo to the next due to the changing height of the airplane above the ground surface.

The simplest way to determine the scale of an aerial photo is to measure the distance between two points on the photo and compare that to the distance between the corresponding points on a map of known scale. If the distance between two points on a photo of unknown scale is 2.1 inches and the corresponding distance on a 1:24,000 scale map is 1.6 inches, then solve the following ratio to find the scale of the photo:

Distance on photo/ Denominator of photo scale =
Distance on map / Denominator of map scale

$$1.6/x = 2.1/24{,}000$$
$$x = (1.6)(24{,}000)/2.1$$
$$x = 18{,}286$$

Photo scale = 1:18,286

Types of Film

The three types of film most commonly used for aerial photography are black-and-white, color infrared, and color films.

Black-and-white or panchromatic film is usually shot with a yellow filter for increased haze penetration. Black-and-white photos are excellent for general land use and land cover mapping and have moderately good depth penetration in water.

Color infrared film has been around since World War II but has only come into widespread use in the last 30 years. This is a false-color film that is always shot with a yellow filter. This film-filter combination is sensitive to the green, red, and near-infrared parts of the spectrum and is excellent for distinguishing different types of vegetation. Water and wet soils stand out in strong contrast to surrounding drier soils but color infrared film has poor depth penetration in water bodies (clear water tends to look black). It is not a heat-sensitive film (heat radiation is in the far-infrared portion of the spectrum).

A third type of film is normal color film. Colors correspond roughly to colors seen by the human eye, although haze often seems to wash out the colors a bit. Normal color film has better depth penetration in water than color infrared film but vegetation has a smaller range of colors on normal color film than on color infrared. Table 1 gives examples of the colors that a variety of objects have on both normal color and color infrared film.

Any of the films described above can be useful for a watershed study. However, if wetland mapping is to be done, color infrared film flown in the springtime is the film to have.

Stereoscopic Viewing

The key to extracting the maximum amount of information out of aerial photos is stereoscopic viewing. Stereo viewing more than doubles the amount of information available from a pair of photos. With this technique you can determine the heights of objects and the shape of the land surface.

Stereoscopic vision is achieved by having each eye view an object from slightly different angles. When the eyes are viewing an actual scene in the landscape, the eyes can only use stereoscopic vision out to around 1000 feet. Beyond that, all distance determinations are based on context. That is why distances in deserts and other large open areas are so hard to estimate. If our eyes were spaced farther apart, we would be able to view the landscape stereoscopically out to greater distances.

The stereoscope, in effect, gives you a very widely spaced pair of eyes. Although aerial photos are usually taken at altitudes of from 6,000 to 20,000 feet above the land surface, the spacing between successive photos in a flight line is usually several thousand feet. The stereoscope is a device that allows each eye to view one of a pair of aerial photos, each of which shows a scene from a different angle. Because the ground spacing between photos is so large, the brain is fooled into interpreting the stereo image as that of a nearby scene with very high relief. Thus, hills appear overly steepened and low features stand out above their surroundings. Depending on the scale of the photos, the focal length of the lens, and the ratio of the height of the plane above the land surface to the horizontal distance between photo centers, height differences as low as two to 10 feet may be readily visible.

To view aerial photos with a standard folding pocket stereoscope, line up a pair of adjacent photos from the same flight line, allowing them to overlap so that common features are directly on top of one another (for example, if a pond is shown on both photos, the images of the pond should be one right on top of the other. Next, spread the photos roughly 2.4 inches apart (the distance between the eyes of an average person), parallel to the flight line. Next, set the width of the lenses of a pocket stereoscope to this same distance. Place the stereoscope on top of the parts of the photo pair that overlapped. The long dimension of the stereoscope should be parallel to the flight line. When the scope and the photo pair are properly oriented, the landscape will stand out in exaggerated relief.

If you can get the view into stereo but the images swim around before settling in, or your eyes begin to hurt after a brief viewing, you do not have the photos aligned quite right. Keep adjusting the photos until they come immediately into stereo view when your eyes are placed on the scope. Sometimes you will find that the photos need to be canted a little in order to come into stereo properly. This is because the photos were crabbed when they were taken. For more details on how to line up photos see Soil Survey Staff (1966).

Once the photos are properly aligned, it may help to tape one or both of the photos down to keep them from moving out of alignment. To view parts of the photos with a pocket stereoscope you will need to gently bend (not crease) parts of the photos.

Photo Interpretation

Many people take a more or less casual look at an aerial photo and believe that they have seen all there is to see in it. An experienced interpreter of aerial photos knows that any given photo (or especially any given stereo pair of photos) contains an enormous amount of information regarding landscape history, vegetation, soils, streams, cultural features, etc. The key is to go beyond passively viewing the photos and to begin to actively interpret them.

The distinctive set of characteristics that describe a feature on an aerial photo is called its signature. Signatures are composed of the following elements (adapted from Avery and Berlin, 1992): tone or color, texture, shadow, pattern, association, shape, and size.

Tone refers to the various shades of gray seen on a black-and-white photo and color refers to the range of colors seen on a color photo. It is important to realize that tone or color by themselves will not uniquely identify any feature. For example, on spring-time color infrared photos a dry sand pit, a sandbar in a river, a dry field covered with stubble, and a wet meadow dominated by reed canary grass may all have the same color (white).

Texture is the roughness or smoothness of a feature. An old field growing up in shrubs and saplings has a very rough texture while pavement or a mowed lawn has a very smooth texture.

Shadows often obscure important features but it is useful to remember that the shadow can also reveal information about the object which is casting it. The dark shadow of a shrub on grassy vegetation may be easily visible while the shrub itself has little contrast with its surroundings and is difficult or impossible to discern. Note that on color infrared film shadows tend to be very black and they can completely obscure features, while on black-and-white film one can commonly see some detail in the shadows.

Pattern refers to the arrangement of objects, such as the grid pattern of trees in an orchard, contour plowing on a hillside, or a trellis drainage pattern in a river system.

Association refers to the general association between features, such as the association of toppling trees with an eroding river bank. Trees topple over for many reasons at many different spots on the landscape but if one observes several trees toppling over into the river at a site it is quite likely that the cause is an eroding bank.

Shape is often a very obvious clue to the identity of a feature. The shape of an abandoned oxbow in a floodplain is quite distinctive. Also, on a large-scale photo the shape of an elm tree is very different from that of a sugar maple.

Size is another obvious signature element. Relative size can be estimated by comparison with known objects such as roads, houses, cars, etc. If the scale of the photo is known accurately then actual measurements can be made.

Some of the features that can be spotted on aerial photos when they are viewed in stereo:

a. Shadows of deciduous trees on river
b. Road
c. Riffles, runs, and pools
d. Old channel, now partly abandoned
e. Tree leaning over river
f. Former channels
g. Rip-rap on bank
h. Bedrock
i. Farmstead
j. Culvert under road
k. Conifer woodland
l. Pasture
m. Hayfield
n. Unvegetated bars
o. Vegetated bar
p. Eroding bank with no buffer
q. Large log on bar
r. Tree which has slumped into river
s. Boulder in river

Many further examples of the features which can be discerned on aerial photos are shown in Avery and Berlin (1992) and Soil Survey Staff (1966).

Height Measurement

Using a stereoscope it is possible to roughly measure the height of features such as stream banks or trees, either by comparison with objects of known height (such as houses, cars, or telephone poles), or else by analytical methods involving parallax calculations. For information on making parallax calculations see Avery and Berlin (1992). Using a stereoscope you should easily be able to distinguish differences in height between grasses, shrubs, and trees.

The Need for Field Work

In order to get the maximum amount of information out of a set of aerial photos, a certain amount of field work is necessary. For a large project, a recent set of photos should be obtained early on and reviewed prior to field work. The photos can provide a good overview of land use and land cover in the corridor and may reveal possible locations of alluvial fans, former channels, flood chutes, eroding banks, etc. After going out in the field, again review the photos. This is a good time to review older sets of photos to look for changes in stream planform, etc. This second round of aerial photo study can also help you see the full extent of features seen in the field. For example, a low terrace that you overlooked in the initial photo review may now be easily visible since you encountered it in several spots.

If your organization owns the aerial photos, you may choose to take them out in the field, although it is probably better to make copies and leave the originals in the office (good copies can actually be viewed in stereo, although there is certainly some loss of fine detail). As it can be difficult to keep photos clean and dry, do not take borrowed photos into the field.

Common Flaws Seen on Photos

On some prints of aerial photos the edges are quite dark. Because wide-angle lenses are used for this work, there is significantly less light falling on the edges as compared to the central region of the photos. Therefore, if a simple contact print is made, the edges come out dark and it is difficult or impossible to see details. If you are considering using photos which are dark on the edges, it may be possible to use modern printing techniques to reprint them and eliminate the dark edges.

A large fuzzy white spot on an aerial photo is referred to as a hot spot. This is caused by sunlight being reflected directly back at the camera, causing an overexposed spot. Aerial photographers usually plan their photography to avoid times of day when hot spots are likely to occur. Again, modern printing techniques can at least partly reduce these spots.

No two sets of color infrared photos of the same area ever seem to show the same exact color range. This is partly due to the sensitivity of such film to variations in vegetation and partly due to the fact that the color balance in these photos is sensitive to the temperature and freshness of the developing chemicals. Two prints from the same original made by the same lab on two different days usually have visibly different color balance. If you are unsatisfied with the quality of a photo order, have the processor try again.

Finding Vermont Aerial Photos

Hundreds of aerial photo flights have been made over Vermont since at least as far back as the late 1930s. Some were contracted by the federal government, some by the state, and others by private companies or individuals. The available photo sets range from statewide coverages to sets of a dozen or less photos flown for an engineering project. As an example, at least 18 separate sets of photos of various scales have been flown over all or part of the Town of Plainfield, Vermont.

Since the late 1930s at least eight complete statewide sets of aerial photos have been taken over Vermont (Table D-1)

Table D-1 Statewide aerial photo coverages.

Date	Original Contracting Agency	Current Source	Scale	Emulsion
1939-1942	USGS and USDA	EROS Data Center, APFO	1:48,000	Black-and-white
1962-1964	State of Vermont	Aero Graphics	1:18,000	A
1974-1976	State of Vermont	Aero Graphics	1:20,000	A
1974-1985	Vermont Mapping Program	Vermont Mapping Program	1:30,000	A (first round of orthophoto production)
1978-1980	US Army Corps of Engineers	EROS Data Center, APFO	1:80,000	Black-and-white or color infrared
1985-1987	USGS NHAP	EROS Data Center, APFO	1:58,000	Color infrared
1988-present	Vermont Mapping Program	Vermont Mapping Program	1:30,000	Black-and-white (second round of orthophoto production)
1992-1994	USGS NAPP	EROS Data Center, APFO	1:40,000	Color infrared

EROS = U.S.G.S. EROS Data Center, Mundt Federal Building, Sioux Falls, SD 57198, phone (800) 252-4547, web site <http://edcwww.cr.usgs.gov/eros-home.html>.

APFO = USDA Aerial Photography Field Office, P.O. Box 30010, South Salt Lake City, UT 84130-0010, phone (801) 524-5856, web site <http://www.apfo.usda.gov>.

Aero Graphics Corporation, Box 248, Bohemia, NY 11716, phone (516) 589-6045.

NHAP = National High Altitude Program

NAPP = National Aerial Photography Program

The 1962-64 statewide photos are probably the most widely used set of photos in the state. The photos are of fairly large scale (1:18,000) and most of the frames have very good contrast. Because more of the land was in agricultural use than at the present time, the land was more open and therefore these photos are excellent for studying landforms. They are still being used today by soil mappers and geologists. As part of the project, large-scale photos (1:6,000 scale) were taken of many of the town and village centers.

There are many aerial photo collections in Vermont. The Bailey Howe Library at the University of Vermont maintains a large collection. Several offices in the Vermont Agency of Natural Resources maintain collections. The local NRCS offices usually have particularly good aerial photo collections.

Although these organizations do not loan out photos, they are usually available for public viewing (be sure to call ahead first).

Ordering Aerial Photos

To order photos from the federal government, contact either the USGS EROS Data Center or the USDA Aerial Photography Field Office. The EROS Data Center (phone 800-252-4547, web site <http://edcwww.cr.usgs.gov/eros-home.html>) maintains an aerial photography collection going back to the 1930s. A search of their archives for Plainfield, Vermont turned up 10 sets of photos from 1939 to 1993. The USDA Aerial Photography Field Office (phone 801-975-3503, web site <http://www.apfo.usda.gov>) maintains an archive of aerial photography going back to the 1950s. A catalog of their recent Vermont holdings is in Appendix 2.

Aerial photos can be obtained as either prints or transparencies. Prints are more convenient to use but if maximum resolution is needed, transparencies are best. Prints can be made on heavy or light paper, with the heavy paper being much less subject to curling.

The standard size for aerial photos is the 9 x 9 inch direct contact prints. Although because of the large negative size, high-resolution enlargements up to 36 x 36 inches can also be obtained, the cost is considerably more than for contact prints.

When ordering photography try to make sure that prints are made with a printer that can electronically dodge the prints. This can reduce hot spots and eliminate light fall-off on the edges. Because the EROS Data Center uses these higher quality printers while the Aerial Photography Field Office (APFO) does not, photos should be ordered from EROS Data Center rather than APFO whenever possible.

Storing Aerial Photos

All photos should be kept in clear mylar sleeves. This protects them from fingerprints. The oil from fingerprints makes dust stick on them and the dust then scratches the emulsion, reducing the resolution of the photos. For long term storage, the sleeved photos should be in acid-free folders and should be kept out of direct sunlight. If properly processed and stored, black and white photos should last for many decades without significant fading. Color photos of all sorts will undoubtedly fade over time.

Orthophotos

Aerial photos can reveal an incredible amount of detail about the landscape. However, it is difficult to make accurate measurements on them because the scale continuously changes from the center to the edge of the photo and as the elevation of the ground changes. A special type of aerial photo product known as an ortho-photograph remedies this problem. An ortho-photograph shows much of the detail of an aerial photo but, like a map, it has a constant scale. This enables the user to make reasonably accurate measurements of angles and distances.

Orthophotos are available for all of Vermont at 1:5,000 scale and more detailed 1:1,250 scale orthophotos are available for selected urban areas. The ortho-photography program began in 1974 and most areas have been covered twice since then. Since 1994 the orthophotos have been produced using digital methods and are available in digital format as well as the traditional printed map format. Digital orthophotos are currently available for most of the state. To obtain orthophotos, contact the Vermont Mapping Program at 43 1/2 Randall St., Waterbury, VT 05676, phone (802) 241-3507.

There are limits to what can be seen on orthophotos. They are very useful for determining land use, land cover, and the locations of prominent features and it is easy to measure sizes, distances, and angles. However, many features that can be easily discerned by viewing a pair of aerial photos in stereo are simply not visible on an orthophoto. Also, even though the newer digital orthophotos have very good resolution, they still do not have as fine a resolution as the original photos that the orthophotos were made from. Thus, an orthophoto can show you the location of a stream bank but you will not be able to tell the height of the bank and you probably will not be able to see logs stranded on a sandbar.

Historical Analysis With Aerial Photos and Orthophotos

Aerial photos and orthophotos are powerful sources of historical information for documenting how landscapes have changed over time. They are especially well suited for studies of change in stream channel planform because the stream banks are usually reasonably clear, even on single aerial photos or orthophotos.

Assuming that the features of interest are easily visible on the images, the primary difficulty is to get all of the different images at the same scale so that comparisons can be made. If all of the sources of data were orthophotos, then it would be a fairly simple matter to enlarge or reduce them all to a common scale. Because we do not have orthophoto coverage prior to the 1970s, and because of the distortions inherent in all aerial photos, it is usually not quite that easy. For a small area it is most practical to enlarge or reduce small areas of the photo, one at a time, registering them into position by using landmarks which show up on both the photo and the base map. This can be done either by using an optical instrument such as a Zoom Transfer Scope or vertical sketchmaster or by making overlays of the aerial photos and enlarging the overlays using a copy machine so they match the scale of the base map and then shifting them around on top of the base map on a light table until the landmarks on the overlay match up with their positions on the base map. This is a slow and tedious method but it can yield reasonably accurate results. For large areas, it may be more efficient to use GIS software to produce a digital orthophoto of each date of photography. Possible software for such work includes ERDAS Orthbase and an ArcView extension called Orthrec. Either of these programs would require a digital elevation model of the terrain and scanned images of the aerial photos.

Summary

- The stereoscope is a very powerful tool for photo interpretation.
- Interpret objects by looking at all the signature elements, not just tone or color.
- Field work and photo interpretation go hand-in-hand.
- Statewide aerial photo coverages date back to the late 1930s and early 1940s.

References

1. Avery, T.E., and G.L. Berlin. 1992. Fundamentals of remote sensing and air photo interpretation: Macmillan Publishing Company, New York, 472p.

2. Philipson, W.R., *editor*. 1997. Manual of photographic interpretation: American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 689p.

3. Soil Survey Staff. 1966. Aerial-photo interpretation: Agriculture Handbook 294, U.S. Department of Agriculture, Soil Conservation Service, 89p.