United States
Environmental Protection
Agency

Office of Solid Waste and
Emergency Response

January 2014
www.epa.gov/superfund

Superfund

EPA

Advanced Groundwater Investigations

Workbook

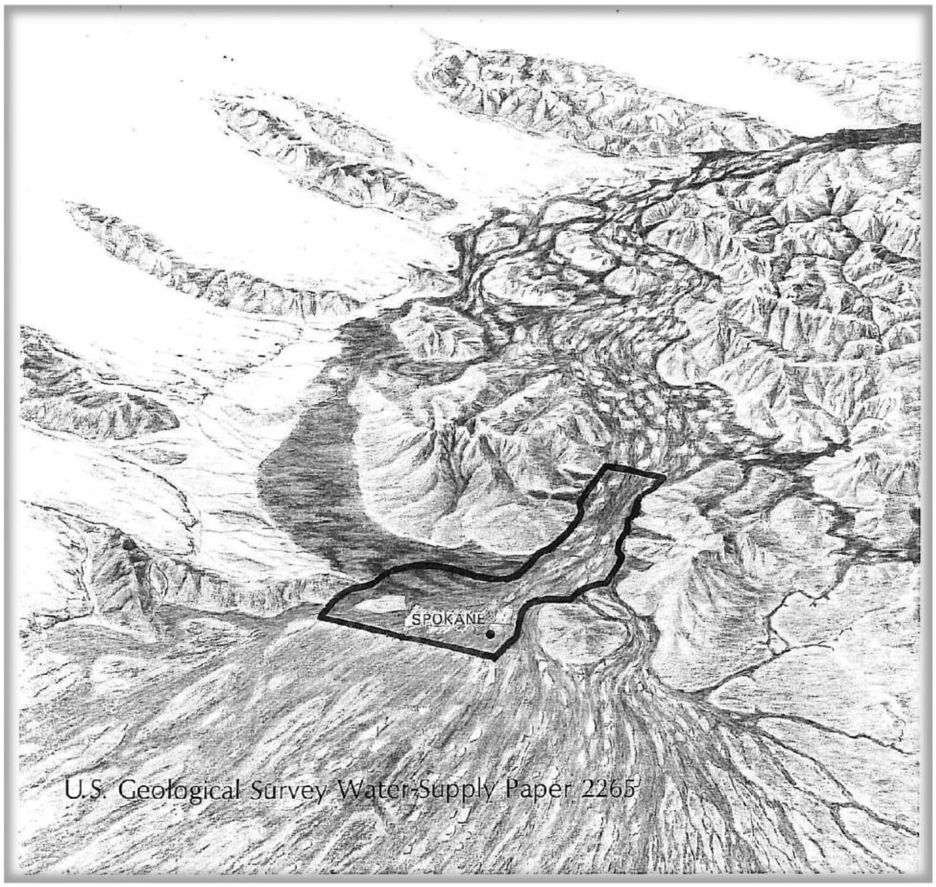


TABLE OF CONTENTS

HYDROGEOLOGIC SITE INVESTIGATION EXERCISE

INTRODUCTION

The site investigation exercise study area is an approximate 12-square-mile area north and east of Mead, Washington, including a portion of the City of Mead. The site covers all or parts of Sections 23, 24, 25, 26, 27, 34, 35, and 36 of Township-27-North and Range-43-East (T-27-N, R-43-E) and Section 1, 2, 3, 10, 11, and 12 of T-26-N, R-43E. Because no section numbers are repeated, all further location references will use only the section number and will not include the township and range designation.

Each well has been assigned a number (1 through 70) to assist in locating the wells on the topographic map and locating the corresponding well logs, geophysical logs, and analytical data (where available) in the notebooks. An overlay is provided that shows the assigned well numbers superimposed over the topographic map. References to wells in the problem scenario will use the assigned numbers.

This discussion will provide the following information about the exercise:

- Physical setting, including site geology and aquifer characteristics.
- Agricultural, commercial, and industrial development.
- Exercise scenario, including site investigation information, groundwater contamination, and well logs.

All of the following site information and site characteristics are fictional, including agricultural, commercial, and industrial facilities and specific facility names; farm names; hazardous material or petroleum releases; facility hazardous material use, handling, or on-site storage; well locations; well uses; and site geology. Any names or circumstances similar to any existing or former facilities in the exercise are coincidental.

EXERCISE GOAL

Locate the possible sources of the chlorinated compounds detected in the lower aquifer of the new municipal well.

PHYSICAL SETTING

The City of Mead is located in eastern Washington, approximately 10 miles north of Spokane, Washington, and east of the Little Spokane River. The population is less than 10,000. The site topography is generally level, except for the east-west trending valley created by Deadman Creek, located on the southern portion of the exercise area, and the Little Deep Creek valley to the west. Farther west of Little Deep Creek is the Little Spokane River. To the northeast is Green Bluff, with topography 300 feet higher than the exercise area.

The surficial geology of the exercise area is unconsolidated Quaternary glacial materials deposited on the Tertiary Latah Formation. Two aquifers are within the Quaternary glacial material. A lower confined aquifer consisting of unconsolidated gravel, sand, and silty clay. The lower aquifer is immediately above the siltstone and claystone Latah Formation. Above the lower aquifer is glacial-deposited lacustrine clay. A shallower unconfined upper aquifer is above the lacustrine clay and consists of glacial outwash sands and gravels.

Aquifer Information

The lower aquifer is a high-yielding, confined aquifer. Numerous wells and borings either produce from or have penetrated the lower aquifer, including two municipal water supply wells, domestic water wells, agricultural irrigation wells, industrial water supply wells, and site investigation monitoring wells. When agricultural irrigation wells were initially introduced to the Mead area, some of the irrigation wells produced from the upper aquifer. However, because these wells caused severe seasonal drawdowns in the upper aquifer, the regional water resources board later required that all irrigation and industrial wells produce from the lower aquifer. During the drilling of the deeper irrigation wells, local drillers discovered that the high-yielding sand and gravel deposits of the lower aquifer were not always present. Nonproductive irrigation and industrial wells were either properly abandoned or completed in the upper aquifer for domestic use. The water resource board required that geophysical logs be run to ensure that all irrigation and industrial wells were producing from the lower aquifer.

The lacustrine clay deposit is gray, plastic clay with a varved structure. The clay has a very low permeability and does not yield usable quantities of groundwater.

The upper unconfined aquifer consists of glacial flood deposit sediments described as poorly sorted boulders, cobbles, gravel, and sand. The depth to the upper aquifer groundwater ranges from 10 to 90 feet below ground surface. Seasonal springs, shown on the topographic map, can be found where the upper aquifer is exposed along the valley walls of Little Deep Creek and Deadman Creek. Many older domestic potable wells are still producing from the upper aquifer; however, many of the upper aquifer domestic wells are no longer in use because of the expansion of the City of Mead Water Works system.

Area Development

For many years, the Mead commercial base was agricultural. Within the past 25 years, an industrial park was built north of town in the eastern half (E/2) of Section 26. Three industrial facilities were constructed at the park: an electrical component manufacturing facility; a metal fabricating facility; and, a chemical blending facility. Each occupies a 40-acre tract. Other industrial facilities in the Mead area include a machine shop located in the southwest quarter (SW/4) of Section 35 and a state highway department maintenance shop located at the Mead airport (north portion of Section 3). An abandoned wood treatment facility is located in the northwest quarter (NW/4) of Section 34.

PROBLEM SCENARIO

A City of Mead water supply well, completed in 1965, produces from the lower aquifer. This well is located in the center of the southern half of Section 3 (identified as Well #65). An additional municipal water supply well was needed because of the continued expansion of the

City of Mead Water Works system. The City of Mead completed a new water supply well in the southwest quarter (C-S/2-SW/4) of Section 2 (Well #56). The City of Mead retained a hydrogeologic consulting firm to supervise the drilling and well construction and to perform an aquifer stress test of the new well. The well was successfully completed in the high-yielding lower aquifer, and an aquifer stress test was conducted.

The Spokane County Health Department collected water samples from the new well before the new municipal well entered into service, which were analyzed for select organic compounds, inorganic compounds, microbiological specimens, pesticides/herbicides, and radioactive isotopes. The analytical results were compared with the National Primary Drinking Water Standard maximum contaminant levels (MCLs) and showed detectable levels of trichloroethylene (TCE) at 0.046 parts per million (ppm) and dichloroethene (DCE) at 0.009 ppm, which exceed the MCLs. The analytical results are presented with the well logs. The MCLs are 0.005 ppm for TCE and 0.007 ppm for DCE.

TCE and DCE are chlorinated solvents. Chlorinated solvents are widely used as degreasers. DCE can be a decomposition compound of TCE and is occasionally found in association with TCE contamination. The City of Mead requested a subsurface investigation be conducted to identify the source of the chlorinated compound contamination because TCE and DCE concentrations exceed the MCL.

The investigation included collection of all available well log information from the City of Mead Water Resource Board; identification of area Resource Conservation and Recovery Act (RCRA) facilities and records; records review of active state or federal Superfund sites; and records review of leaking underground storage tank (UST) site investigations.

Well Logs

Well logs collected from the water resource board include a wide assortment of data. One or more well log types was available for each well, and the log quality varied from handwritten driller logs to open-hole geophysical and geological logs.

As previously discussed, the water resources board required at least one geophysical log for all industrial and irrigation wells producing from the lower aquifer. However, some irrigation wells entered service prior to this order. The well owners ran a cased-hole gamma-ray log for those wells. The original driller logs for some irrigation wells are not available. The industrial water supply well information includes open-hole gamma-ray log and resistivity logs. A full suite of logs (open-hole geophysical and geological logs) is available for the two municipal wells (Wells #56 and #65). Logs for geotechnical borings completed during development of the industrial park are also available. Consider all well log information accurate for this exercise.

RCRA Facilities

RCRA information shows TCE used in various quantities at many commercial and industrial sites. TCE is used at each of the three facilities located at the industrial park (Section 26), the machine shop (Alpha Manufacturing) located in the southwest quarter (SW/4) of Section 35, and the state highway department equipment maintenance facility located near the airport in the northeast quarter (NE/4) of Section 3.

Monitoring wells were drilled near the state highway department equipment maintenance facility and the machine shop because of their proximity of to the new municipal water supply well. The site investigation consisted of completing two monitoring wells on the airport property (Wells #62 and #63) in the north half of Section 3 and one monitoring well immediately south of the machine shop (Well #53) in the northwest quarter of Section 2. Each of these wells was sampled and analyzed for volatile organic compounds (VOCs). The analytical results are presented with the well logs. Consider all analytical data accurate for this exercise.

<u>Site Investigations and USTs</u>

The initial review found two ongoing state Superfund sites and two leaking UST sites within the exercise area. The state Superfund sites are a former unregulated dump known as the Peone Road Dump located in the SE/4 of Section 2 and the former wood treatment facility located in the north half of Section 34. The leaking UST sites include a retail gasoline station in the NE/4 of Section 34 and the Colbert School in the SW/4 of Section 26.

Before the new municipal water supply well was sampled, no work had started at the Peone Road Dump site. The state immediately began a site investigation because of the nature of the groundwater contamination reported by the City of Mead. The initial investigation included drilling six monitoring wells in the immediate area of the former dump and collecting groundwater samples from the upper aquifer and lower aquifer (where present). Twin wells were drilled in the immediate area of monitoring wells MW-2 and MW-3 (Well # 58 and #59) (designated MW-2A and MW-3A) and screened in the upper aquifer because both wells encountered both the upper and the lower aquifer during drilling. A verbal report from the state indicated that TCE was most likely released at the Peone Road Dump. Analytical results for groundwater were provided by the state and are included with the well logs.

The state collected groundwater samples from five existing wells located in the immediate area of the former dump during the Peone Road Dump site investigation and analyzed the samples for VOCs. The five wells were in use before the site investigation and consist of two wells in Section 35 (Well # 38 [C-S/2-S/-2] and Well #39 [C-SE-SE]), two wells in Section 1 (Well #48 [C-NE-NW] and Well #49 [C-NW-NW]), and an irrigation well located in the C-SW-NE of Section 11 (Well #69). The analytical results are presented with the well logs. Requests to collect groundwater samples for analysis of VOCs from the other industrial, irrigation, and domestic wells were denied.

EXERCISE GOAL

Develop a subsurface Conceptual Site Model to locate the possible source or sources of the chlorinated compounds detected in the lower aquifer of the new municipal well.

Aquifer Stress Test Data

Aquifer Test - Municipal Well, Mead, WA Pumping
rate Q = 1,000 gpm
Observation well 400 feet from pumping well

time - t - (minutes)	drawdown - s- (feet)
6	0.04
9	0.11
12	0.14
15	0.21
20	0.32
25	0.39
30	0.48
40	0.57
50	0.72
60	0.75
70	0.85
80	0.89
90	1.00
100	1.12
120	1.20
150	1.41
200	1.60
300	2.00
400	2.19
500	2.40
600	2.52
700	2.65
BOO	2.76
900	2.85
1,000	2.95
1,800	3.40

Aquifer Stress Test Data

Aquifer Test - Municipal Well, Mead, WA Pumping rate Q = 1,000 gpm Observation well 1,500 feet from pumping well	
time - t - (minutes)	drawdown - s - (feet)
20	0.07
30	0.10
45	0.21
60	0-.29
80	0.42
110	0.56
160	0.80
220	1.00
310	1.19
460	1.41
610	1.59
850	1.80
1,150	2.00
1,800	2.28

Aquifer Test - Municipal Well, Mead, WA Pumping rate Q = 1,000 gpm; t = 1,500 minutes; b = 75 feet	
distance - r - (feet)	drawdown - s - (feet)
1,500	2.20
2,000	1.85
2,850	1.46

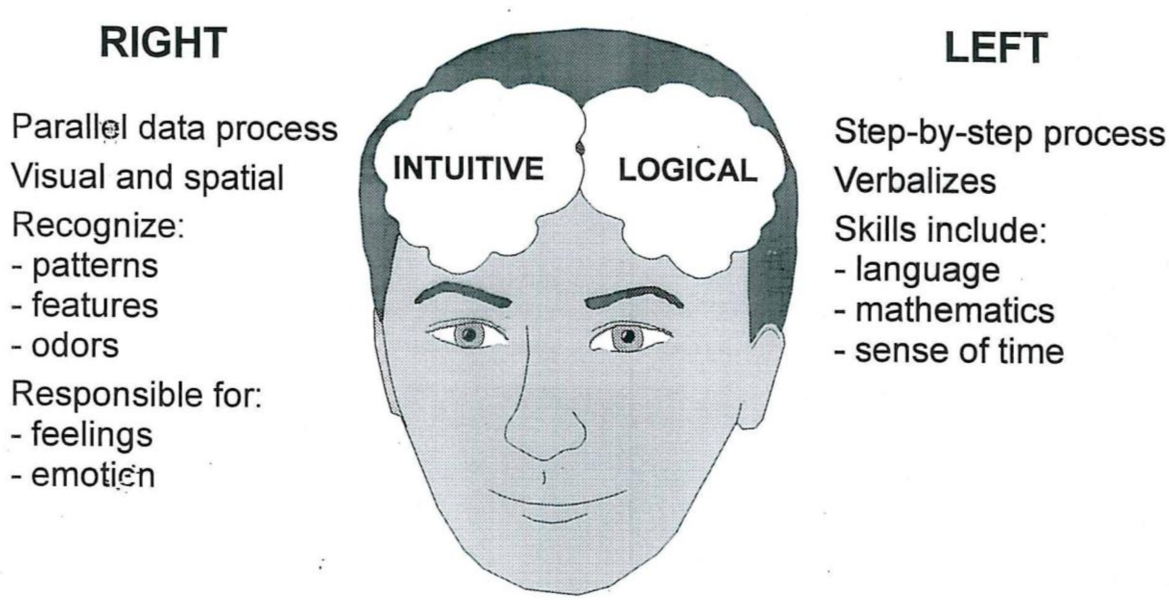
CREATIVE THINKING AND PROBLEM SOLVING

When an individual or project team investigates a subsurface contaminant fate and transport problem, a certain amount of creative thinking and problem solving skills are used. Creative thinking is also used when producing maps, cross-sections, site diagrams, and conceptual site models (CSM). These creative thinking skills are needed to infer the information between known data points. The purpose of this section is to explain how this creative thinking and problem-solving process works so that those skills can be improved or enhanced.

An important part of understanding how the creative thinking process works is to understand how our brain functions. Research conducted in the 1950s by scientists Roger W. Sperry, David H. Hubel, and Torsten N. Wiesel (who shared the Nobel Prize as a result of this research) showed the human brain processes information using one of two hemispheres, the right side or the left side. This research showed each hemisphere processes information in a contrasting but complementary method. One hemisphere is more creative and intuitive, and the other is more logical. For a right handed person, the left side of the brain process information in a step-by-step process while the right side of the brain processes information in a parallel or non-linier process. The opposite is true for a left handed person.

Furthermore, the left side of the brain is responsible for the logic and mechanical skills such as language, mathematics, and sense of time as shown in the figure below. The right side of the brain is responsible for intuitive and creative skills and is more visual and spatial. The right side recognizes pattern, features, and odors.

The creative thinking process uses skills from both hemispheres of the brain.



The creative thinking and problem solving process is discussed in an excellent book by Betty Edwards, PhD: "Drawing on the Artist Within." This book is written to teach people how to draw but also provides great insight into the creative thinking process. Dr. Edwards discusses the thoughts and writings of 19th and early 20th century physiologists, mathematicians, and scientists and concluded that the creative thinking process involves five steps: (1) first insight, (2) saturation, (3) incubation, (4) illumination, and (5) verification.

Each of these steps takes place in one or the other of the brain's hemispheres, and each will be further discussed.

Step 1, First Insight

For a right handed person, the first insight step involves the right side (or creative side) of the brain. A person looking at a problem may ask what is missing because the creative side can process a large quantity of information quickly and can recognize patterns. This question requires a certain amount of intuition to understand that something is missing. This intuition is developed by having experience with that particular problem or subject.

Below is a series of maps to demonstrate first insight. Each map uses the same data points, but each map represents a different geologic province. Therefore, when a CSM or surface contour map is developed using a set of data points, the professional or project team should have a basic knowledge of the site to complete the map.

To emphasize the point of "first insight," if a person were asked to draw a surface contour map with just data points and no other information about the site, the end result might look like Figure 1.

Mechanically this map is correct, but does it accurately depict the surface?

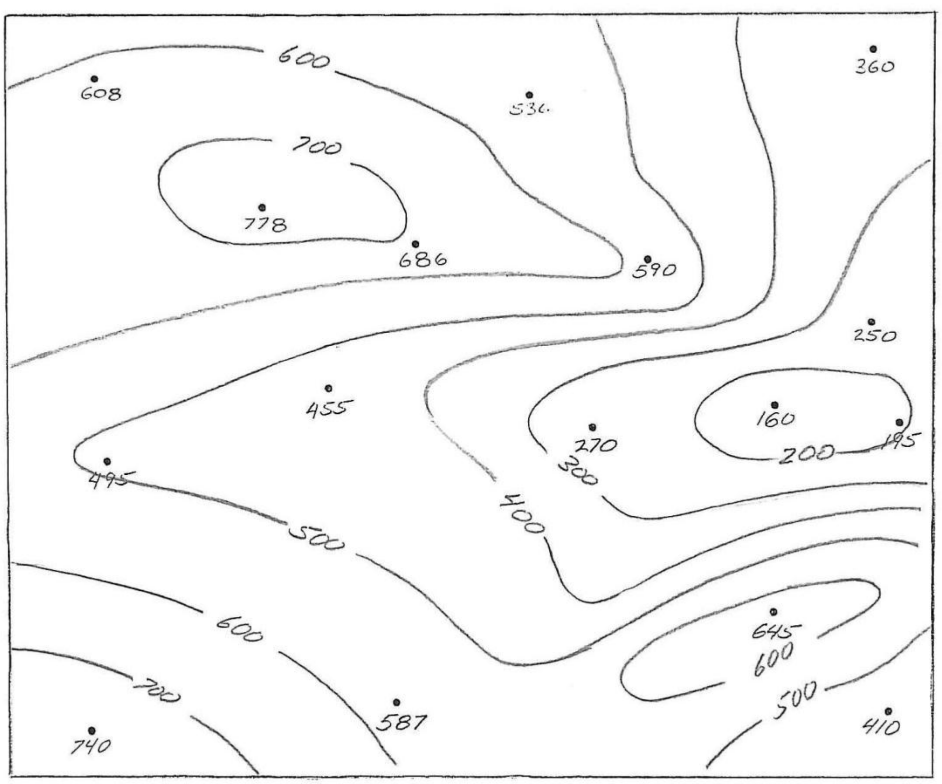
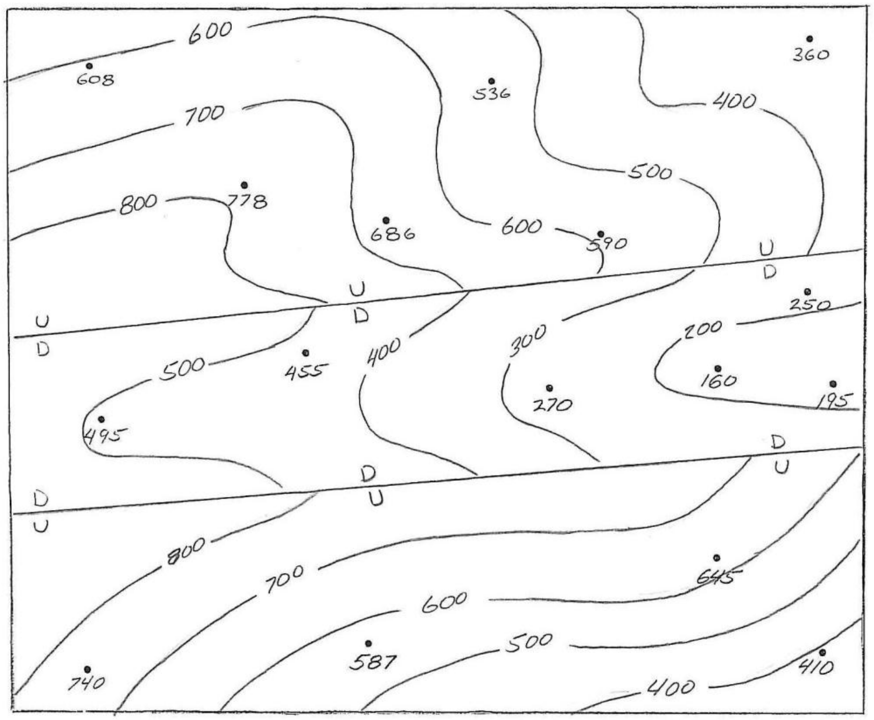


Figure 1

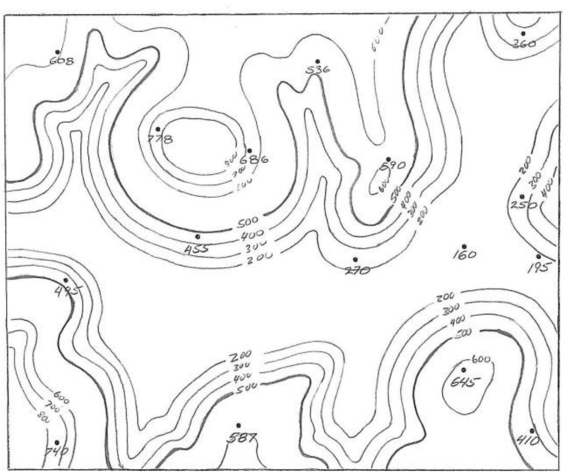


If the project team had knowledge and experience with the site and knew the area to be highly faulted, the map could be completely different.

Shown in Figure 2 is a map using the same data points but depicting a faulted graben.

Figure 2

If the project team's first insight is that the site is located in an area of a deeply incised, youthful valley or in a parallel valley and ridge province; the maps may look like Figures 3 and 4:



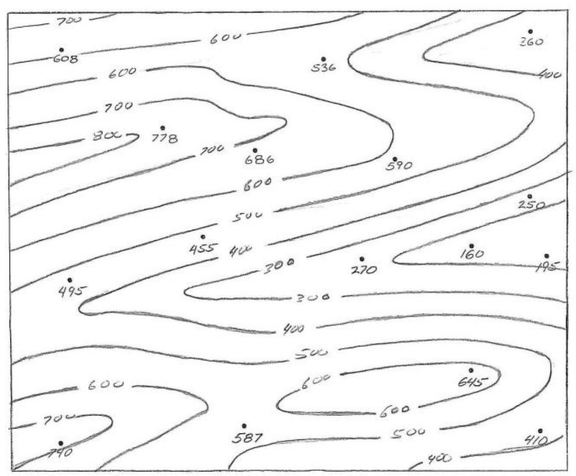


Figure 3 **Figure 4**

The point is: when the professional is asked to develop a surface map, a certain amount of first insight is used.

With the mapping problems just shown, if given a blank map with just the data points, the brain's right side would conjure a mental image. This image would be based on site knowledge. With no site knowledge, a likely map would look like Figure 1. The more experience a person has with the site, the easier it is to complete the map. Professional experience develops the intuitive feel and first insight.

Step 2, Saturation

The second step of the creative thinking and problem solving process is saturation. Some may think of this as the first step of the process because the first insight step is done instantly and subconsciously and the second step, saturation requires more time.

With saturation, the left hemisphere of the brain takes over and gathers, sorts, and categorizes information regarding the problem. This step is often the most arduous and time consuming of the problem solving process. Thomas Edison referred to this stage when he said “invention is 99 percent perspiration and 1 percent inspiration.” Ideally, saturation continues until all information is consumed.

However, the amount of data is overwhelming with some problems. When this occurs, the brain loses its ability to focus on the problem. Anxiety and frustration overtake the left hemisphere’s ability to solve the problem logically. The left side is blocked. Often at this point, the professional will push the problem aside for a while.

You may have reached this point with certain problems. But saturation must be reached before the third step begins.

Step 3, Incubation

The third stage is incubation, which begins just as the left hemisphere loses its focus.

Even though the left side of the brain pushes away the problem, the right side of the brain has not let go. Again subconsciously, the problem is turned over to the brain’s right hemisphere. The right side continues to process the information that was collected during the saturation period. The right side in its quiet, timeless way continues to massage the data looking for a solution to the problem or the key that places the pieces of the puzzle in the proper position.

During the saturation period, the left side of the brain is conscious of time, but the right side of the brain in not burdened with time during incubation. The incubation period is timeless.

Step 4, Illumination

Then out of the blue, “boom” problem solved. This step is the illumination stage or sometimes called the “eureka moment.” This illumination stage may have happened to you and your first response may have been “I’ve got it” or “where did that come from”?

“Where it came from” was that the right hemisphere solved the problem and presented the solution. The right side of our brain with its subconscious, creative, intuitive, and timeless process came through again and worked the details to completion. Great! Except there is one more step to the process, verification.

An interesting sidebar to the illumination phenomena is how it comes about. Illumination is often accompanied with outside visual stimuli such as when a person is driving or walking. The reason is the left side of the brain is occupied with just enough mechanical and semi-automatic chores, such as driving to or from work or biking a familiar route, that the right hemisphere is free to mull over the problem. Visualization is a very important stimulus for creative thinking. That is why walking, running, biking, or driving helps stimulate the creative thought processes.

Step 5, Verification

The final step, verification, is back to reality. After the euphoric moment that you solved the problem, it must be verified. Hence the final 99 percent perspiration, or verification stage, begins. The logical left brain is given the task of proving the idea. In some cases, the data must be re-examined to determine that the right side did indeed solve the problem. In other cases, data gaps appear that must be filled. But the end result is a more complete CSM.

This step is also where the solution to the problem must be verbalized or communicated to the project team or stake holders, which can also be an arduous task.

SUMMARY

Understanding the five stages of creative thinking will help you enhance the creative thought process.

Some things that enhance the creative process and help the process to work effectively include:

- A comfortable state of mind,
- Comfortable surroundings,
- Correct and complete information, and
- Flexible thinking, the ability to ask "what if"?

Some things that stifle the creative process include:

- Fear of failure and intimidation
- Deadlines
- Interruptions such as telephones, e-mails, and endless meetings,

These unfortunately are part of our lives, so to be creative one must find the time and place to reduce these interferences.