Gray Fischer
What's happening? Why has an emergency meeting of Yellowstone Park Watch been called? Maya, I see you're also here—please fill me in!

Maya Crowbes
I'm just as confused as you are, Gray; what *is* going on, Doc? Doc?

Beadle
Sorry, my friends, I've been lost in thought. I called you because I received a strange message this morning. Go ahead and read it aloud.

Gray
"To Dr. Abraham Beadle, Chair, Yellowstone Park Watch: Help! The waters of Yellowstone National Park are in danger. I'll be at your office at 10:00 a.m. to discuss the matter. P. S. I suspect foul play!" That's all there is except the signature, which reads "V. DeRama."

The writer of the note is concerned about which natural resource?

Maya Wait a second! That initial “V” isn’t short for *Vi* by any chance? As in Viola DeRama, the millionaire heiress who thinks she is a scientist and sees villainy around every corner?

Beadle
One and the same, I believe.

Gray
Who on earth is Viola DeRama?

Beadle
Where have you been, Mr. Fischer? Last year Ms. DeRama watched Old Faithful Geyser erupt, then set a stop watch for one hour later. When the geyser failed to go off at the sound of her alarm, she called a press conference, reporting that foul play had occurred and Old Faithful was in trouble. If Viola had thought to check her information, she would have learned that, despite the myth, Old Faithful has *never* erupted at exact hourly intervals. The period of time between eruptions ranges from 45 to 120 minutes, though the average is 92 minutes.

Glossary
villainy—acts of wickedness

Does Old Faithful Geyser erupt every sixty minutes?

Maya
Not to mention the time Viola insisted on speaking at my school and told students the orange color found around many of Yellowstone's hot springs is *lava*, red hot lava. Then she hinted that there was a plot to hide this information from the public! Although it's true the park has had many volcanic eruptions in the past, Vi prefers to ignore evidence that the last lava flow in Yellowstone occurred about 70,000 years ago. When I argued that most of the colors are actually microscopic living creatures such as algae and bacteria, Vi replied that microorganisms are too small to be seen without a microscope. This is true if we're talking about single individuals, but she either can't or *won't* recognize that the bright colors are due to trillions of these tiny life forms grouped together!

Glossary
algae—photosynthetic microorganisms which are mainly aquatic and differ from plants because of a lack of true stems, roots, and leaves

bacteria—unicellular microorganisms that are members of Domain *Bacteria*

microorganism(s) tiny life forms such as bacteria or algae; individuals are usually not visible to the naked eye

What causes most of the colors found around Yellowstone's hot springs?

Beadle
Then there was the time Viola DeRama—

Gray
Alright! Alright! I get the general idea. Do you think this emergency message is more of the same?

Maya
Who can say? Vi *did* accurately report a sighting of the bison known as Rosie last spring and it was exciting to learn that Rosie now has a calf.

Beadle
Ms. DeRama also zeroed in on Neva Riviera when that lady was here last winter to discuss geothermal research projects. No one paid attention at the time, especially when Viola said that she and Neva spent a very pleasant half hour chatting about Neva's new shoes—but it did turn out to be true. Rumor has it that the Yellowstone Ministry of Mysteries would have dearly loved to have had a word with Ms. Riviera.

Gray
So this meeting today may be a complete waste of time!

Beadle
Yes, but since the lady herself has just arrived, let's find out what she wants.

Glossary
Neva Riviera—a character, reputedly a pirate, who has had several previous encounters with the Yellowstone Ministry of Mysteries

geothermal—having to do with heat from the Earth

Who was in Yellowstone to discuss geothermal research projects?

Beadle
Hello, Ms. DeRama, please come in. We're interested to learn more about your concerns regarding the waters of Yellowstone.

Viola DeRama
You must be Abraham Beadle, but who are these other people?

Beadle
They are members of Yellowstone Park Watch. We are all volunteers, drawn together by an interest in preserving our first national park. I'd like to introduce Maya Crowbes, a fifth grade teacher who is interested in all things microscopic—especially the microorganisms of Yellowstone.

Maya We've met.

Viola Have we? Oh, I don't think so.

Maya You gave a presentation at my school last spring—

What is the main interest of Yellowstone Park Watch?

Viola
I've been a featured speaker so many times that I don't remember individual talks. Now, who is this young man?

Beadle
This is Grayling Fischer, a college student who knows a lot about the fish of Yellowstone.

Since you contacted me directly, you must already know I have an amateur interest in aquatic macroinvertebrates—visible animals that lack a backbone and live in water. Many types of insect larvae are aquatic macroinvertebrates. "Larvae" refers to the youthful stage of newly hatched insects before they change into their adult forms.

Viola
You are no amateur—you're a doctor!

Beadle
Ah, but my interest in macroinvertebrates is not how I earn my bread and butter. I am a history professor at our local university.

Now, let's get on with things! Your note sounded urgent.

Glossary
aquatic—having to do with water

macroinvertebrate(s)—a visible animal that lacks a backbone

larva(e)—newly hatched insects that are still without wings

Give an example of a macroinvertebrate.

Viola
My business *is* urgent. I have bad news—very bad news, indeed! Obsidian Creek, a small stream in Yellowstone National Park, is missing important bugs—and I suspect foul play!

Gray
Missing *bugs?*

Viola
The larvae of stoneflies, to be exact—which spells trouble with a capital "T!"
The absence of these creatures indicates Obsidian Creek is damaged—in fact, it's fatally flawed!

Gray
Alright, I'll bite. What's wrong with it?

Why does Viola suspect foul play has occurred at Obsidian Creek?

Viola
Obsidian Creek begins west of Nymph Lake and flows north to the Gardner River. A few miles from its source, things go downhill for this little stream.

Maya
Well, most creeks do flow downhill, you know.

Viola
This is *not* a laughing matter! I've run across scientific data proving the water in parts of this stream is degraded—or if that's too fancy a word for *you*, Ms. Crowbes, *polluted.* There must be a source of industrial waste hidden from the public! Such environmental abuse might have remained a deep, dark secret, if it weren't for the stoneflies!

Beadle
My dear Ms. DeRama—

Viola
Don't you "my dear Ms. DeRama" *me*! Oh, *look* at your blank faces! Surely, you, Dr. Beadle, can explain the importance of a stonefly as it relates to water pollution.

Glossary
degrade(d)—to lower the quality of something

Where does Obsidian Creek begin?

Beadle
Yes, of course. Animals are often more finely-tuned to changes in an environment than humans. Once upon a time, canaries were taken into coal mines to detect the presence of dangerous gases. These birds are very sensitive to changes in air quality, so the miners could judge whether the air was safe to breathe by observing its effects on the canaries.

In a similar manner, aquatic macroinvertebrates have different sensitivities to water pollution. Both those macroinvertebrates that are sensitive to and those tolerant of pollution can live in a stream with good water quality. With increased pollution, however, fewer sensitive creatures will be found. If the water quality is very poor, only those macroinvertebrates that are tolerant of pollution will survive.

Glossary
tolerant—accepting of the presence of something

What type of bird did miners use to detect changes in air quality?

Beadle
These living indicators give us a “heads-up” on changes in the stream’s environment that could affect larger animals and even humans—so it’s important to pay attention to them!

Maya
And stonefly larvae are sensitive to pollution?

Beadle
Yes. “EPT” is an abbreviation for *Ephemeroptera*, *Plecoptera*, and *Trichoptera*, insect groups affected by many kinds of pollution. The common names for EPTs are mayflies, stoneflies, and caddisflies. A greater number of different types of EPTs usually indicates better water quality.

Viola
Now that even Ms. Crowbes understands, take a look at this! This data was collected from four sampling locations along Obsidian Creek! There are very few EPT species in Site 3—and almost *none* in Site 4!

Glossary
EPT—abbreviation for *Ephemeroptera*, *Plecoptera*, and *Trichoptera*, insect groups affected by many kinds of water pollution

Ephemeroptera—scientific name of mayflies

Plecoptra—the scientific name for stoneflies

Tricoptera—the scientific name for caddisflies

Why should you pay attention to changes in the type of bugs found in a stream?

Viola
According to the Hilsenhoff Biotic Index, the water quality in both these sites is very, *very* poor!

Gray
Wait a minute—what index is this?

Beadle
The Hilsenhoff Biotic Index, or HBI, measures the health of a stream on a scale from 1 to 10. A value of 1 suggests the presence of a macroinvertebrate community that is very sensitive to pollution, meaning that the water quality is excellent. A value of 10 suggests the opposite. Let me have a look at your data, Ms. DeRama.

Viola
I'm shocked, absolutely *shocked* that such a polluted stream is flowing unchecked through Yellowstone National Park! It's enough to make me speechless!

Maya
I wish!

Glossary
Hilsenhoff Biotic Index (HBI)—a measure of the health of a stream on a scale of 1-10 (with 1 being most healthy) that is based on the macroinvertebrate communities present

What is measured by the Hilsenhoff Biotic Index?

Gray
I admit this information is troubling. Are you sure it's accurate?

Viola
Of course it's accurate! But I have even worse news! This isn't the only Yellowstone stream that's in danger—the Firehole River is also polluted! What a shame! The Firehole is one of the most beautiful rivers in Yellowstone! Why, even its name refers to the dramatic scenery—the hot springs and geysers—surrounding it!

Beadle
Don't be too sure of that. Early trappers used the word "hole" to mean broad, flat valleys, and some historians think "Firehole" is simply another way of saying "Burnt Hole." You see, in the early 1800s, a large fire occurred around present-day West Yellowstone, Montana. The lower part of the Firehole River, now known as the Madison River, flowed through the burned area, so the name might have been transferred to the valley upstream.

Where does the name "Firehole" come from?

Viola
Dr. Beadle, I appreciate your expertise, but now is *not* the time for a history lesson! The person who collected the Obsidian Creek data said the Firehole River shows similar trends. *I'm* sure industrial pollutants have been poisoning both these streams for years!

Beadle
Ms. DeRama, who *did* collect the Obsidian Creek data?

Viola
Dr. Calvin Farnheid, a former associate. Maybe you know the name?

Beadle
Dr. Farnheid is one of the most respected researchers in the Yellowstone Ministry of Mysteries! If this is his work, there is no question but that it's accurate!

Why hasn't he made this data public?

Viola
I suspect the Yellowstone Ministry of Mysteries is deliberately concealing vital information!

Glossary
pollutant(s)—a waste material that contaminates water, air, or soil

Who collected the data on Obsidian Creek?

Beadle
That's a grim idea, Ms. DeRama, and one that goes against everything I know about both Dr. Farnheid and the YMM. Nevertheless, I'll arrange a meeting with Dr. Farnheid to discuss this. In the meantime, we'll collect our own data on the Firehole River.

Ms. DeRama, will you accompany us?

Viola
Oh no, I wouldn't dream of interfering with your work! Besides, I already know what you will find. An expert has already stated that the Firehole River is so polluted no animals can live in it.

Maya
Which expert? Surely not Dr. Farnheid!

Viola
No, this report was written over a hundred years ago by C. W. Cook. What *do* you teach in school, I wonder?

How does Yellowstone Park Watch intend to investigate if the river is in danger?

Beadle
Ms. DeRama is talking about notes written during the 1870 Folsom-Cook-Peterson Expedition. They read, “Although we experienced no bad effects from passing through the ‘Valley of Death,’ yet we were not disposed to dispute the propriety of giving it that name. It seemed to be shunned by all animated nature. There were no fish in the river, no birds in the trees, no animals—not even a track—anywhere to be seen; although in one spring we saw the entire skeleton of a buffalo that had probably fallen in accidentally and been boiled down to soup.”

Gray
Viola, despite C.W. Cook’s report, I promise the Firehole River has plenty of life both in and around it. If you come with us, you might change your mind about quite a few things.

Viola
No, I must be off to talk to my lawyers about a lawsuit! Au revoir.

Glossary
au revoir—French for “good-bye”

How did members of the 1870 expedition describe the valley of the Firehole River?

Gray
But—

Maya
Quit trying to convince her and let's get organized! Before we go, we'll need to decide where to collect our samples.

Gray
I guess you're right.

Maya
Then take a look at this map. I suggest we begin at Kepler Cascades.

Gray
If the river really is showing signs of pollution, the problem may be much further upstream. The Firehole begins in a marshy subalpine basin at Madison Lake and runs down the north-facing slopes of the continental divide. It flows about 7 miles or 12 km before reaching Lone Star Geyser—and from Lone Star, it's still another 2 .5 miles to Kepler Cascades.

Glossary
subalpine—the mountain regions higher than foothills, but lower than tree lines

continental divide—a divide separating river systems that flow to opposite sides of a continent

Where does the Firehole River begin?

Maya
Yes, but Kepler Cascades is the first place where the Firehole River runs beside the main park road, so it will be easy for us to sample it there. Also, it makes sense that the road could be the source of pollution. Prior to this point, human access to the river is limited.

Gray
What do you think, Doc?

Beadle
I think Maya is right. If we find a serious problem even there, we can always return and hike upstream. Also, I suggest our second sample site should be the Upper Geyer Basin—home to Old Faithful.

Where does the main park road first meet the Firehole River?

Maya
Old Faithful and hundreds of other geysers, such as Beehive, Castle, Riverside, and Grand, not to mention numerous hot springs! All these hydrothermal features attract millions of visitors every year. The Firehole River runs through this area, so it is a logical place to examine the stream's water quality.

Gray
Very good—and Midway Geyser Basin should be Sample Site 3. Midway is approximately halfway between Kepler Cascades and the junction of the Firehole and Gibbon Rivers, so it's a convenient reference point for us.

Glossary
hydrothermal—having to do with hot water

Name three geysers in the Upper Geyser Basin?

Beadle
The Firehole River swimming area should be Sample Site 4. Many people come here to bathe in the summer, so it's a good place to look for signs of questionable water quality.

Last, but not least, let's sample the area around Firehole Falls. Along the way, we'll take temperature readings, examine the stream's water chemistry, and observe the fish, microorganisms, and aquatic macroinvertebrates living at each site. We'll plan on meeting with Dr. Farnheid in exactly one week.

Gray
Then the sooner, we get moving, the better! As Sherlock Holmes used to say, "The game's afoot!"

Glossary
Sherlock Holmes—a fictional English detective

Where is a popular place to bathe in the river during the summer?

Beadle
May I have your attention, please! I'd like you to meet Dr. Calvin Farnheid, an ecologist at the Yellowstone Ministry of Mysteries. Dr. Farnheid, Grayling Fischer and Maya Crowbes are both members of Yellowstone Park Watch.

Farnheid
It's a pleasure to meet you. Your organization makes many valuable contributions to Yellowstone.

Beadle
Thank you. Since there's no need to introduce your associate, Ms. DeRama, let's get started.

Farnheid
Associate? I don't. . .I mean, she *does* look fam—

Viola
Actually, it's *Dr.* DeRama.

Maya
Doctor? Doctor of *what*?

Glossary
ecologist—someone who studies the relationships between organisms and their environments

Who is present to discuss changes in the Firehole River?

Beadle
Quiet down, everyone! Let's get on with business.

Farnheid
You said you wanted to discuss my research on Obsidian Creek, but I can't imagine how you know about this project.

Beadle
We'll come back to Obsidian Creek in a moment. To be honest, after doing some of our own research, we're now more concerned about the water quality of the Firehole River.

Viola
What did I tell you? I *knew* the Firehole was in trouble! Let me guess—you saw danger signals such as changes in water chemistry, rapid growth of algae, and increases in water temperature.

Beadle
Yes, yes, and yes. In particular, we were dismayed to discover that the temperature of the river increases by 29°F or 15°C in the stretch between Kepler Cascades and the Firehole swimming area!

How much does the temperature of the Firehole River increase?

Farnheid
That much, huh? That *is* impressive!

Viola
You're smiling now, but just wait till my lawyers get through with you!

Beadle
Dr. Farnheid, you may find this information impressive, but *I* find it *alarming*! Changes of this sort are often caused by human activities, such as using a river's water as a coolant in power plants and then returning it to its natural environment at higher temperatures. Cooling water from a large electric power plant would show a similar temperature increase to that which we observed in the Firehole River, but the situation here is even more serious. Power plants use only a small portion of the water in a stream, but in the Firehole River, *all* the water is heated, meaning there are no cool places in which living creatures can hide!

Research has shown that only small changes in a stream's temperature—one or two degrees Celsius—may have serious environmental impacts. These include lowered oxygen levels in the water, changes in the stream's ecosystem, and direct damage to living aquatic creatures. But, surely, *I* don't need to lecture *you* on the consequences of thermal pollution!

Glossary
coolant—something that reduces a system's temperature while the system is operating by conducting away the heat produced

What are three consequences of thermal pollution in water?

Farnheid
Now, hold on a minute! Let's not use the word "polluted" to describe the Firehole River—*or* Obsidian Creek!

Viola
Then what word would you prefer, Doctor: contaminated, ruined, destroyed, degraded, flawed, poisoned, dirty, corrupted, defiled, spoiled—?

Farnheid
How about "altered"?

Beadle
Altered? Ms. DeRama showed us your data on Obsidian Creek! We know that very few EPT species were found in two out of your four sample sites!

Farnheid
So *that's* how my research disappeared! I don't remember Ms. DeRama being an associate, but I do remember seeing her drifting around my study area. . .

Viola
Don't listen to him; he's trying to hoodwink you by changing the subject!

Glossary
alter(ed)—to make different

How does Dr. Farnheid describe both the Firehole River and Obsidian Creek?

Farnheid
Very well, let's talk about both Obsidian Creek *and* the Firehole River. The first thing you need to know is that the information you saw on Obsidian Creek was incomplete and I now have additional data to round out the story.

Here is a chart showing recent average temperatures and pH levels at each of the Obsidian Creek sampling sites. I remind you that pH indicates how acidic or alkaline the water is. Car battery acid has a pH of 1, household ammonia cleansers rank 11, and pure water is neutral with a pH of 7. Although there are exceptions, most living creatures cannot tolerate living for very long in acidic conditions where the pH is less than six or in alkaline conditions where the pH is greater than eight.

Viola
Aha! Here is proof positive that most life forms cannot live in Sites 3 and 4!—the conditions would be similar to hot vinegar or lemon juice! How *dare* the Yellowstone Ministry of Mysteries conceal that this vile stream exists in Yellowstone National Park—a place that is supposed to be preserved in its natural state! Let's sue!

Glossary
pH—a measure of the acidity or basicity of water ranging from 1-14 (1 being strongly acidic, 14 strongly basic) as determined by **p**ercent **H**ydrogen ion

acidic—tending to form an acid, having a pH of less than 7

alkaline—having a pH of greater than 7

How much does the temperature change between Site 1 and Site 4?

Farnheid
Calm down, Ms. DeRama, you just said the magic words.

Viola
What? Sue?

Farnheid
No, you said, "Preserved in its *natural state*." The conditions in Sites 3 and 4 are *not* habitable for many EPT species, but if you consider what Yellowstone's natural state really is, I think you'll agree there is nothing to worry about.

Maya
Natural state—wait a minute! I think I understand! Vi never showed us a map with your sample locations. Do you happen to have one handy?

Farnheid
As a matter of fact, I do. Take a look!

Is Obsidian Creek more acidic in Site 1 or Site 4?

Beadle
The map shows that Obsidian Creek runs through hydrothermal zones at Sites 3 and 4!

Viola
What difference does that make?

Farnheid
All the difference in the world! Yellowstone has over ten thousand hot springs, mudpots, geysers, and steam vents. If water from a hydrothermal system mixes with water in a stream, the stream's temperature, water chemistry, and ecology are all affected. At Site 4, where stream conditions are most severe, Obsidian Creek flows by Roaring Mountain, an area that's very hot and acidic. Therefore, the creek also becomes hotter and more acidic at this location.

Why does the water quality of Obsidian Creek change at Site 4?

Beadle
Now I see that Sites 1 and 2 are further *downstream*, not upstream, as I had assumed. In both areas, your data indicates the creek's temperature and pH have returned to normal levels for a mountain stream.

Farnheid
Yes, and once the creek passes beyond the influence of hydrothermal activity, the EPT species represent a fairly large percentage of the total macroinvertebrates. This is a sign that the water quality in Sites 1 and 2 is good. Obsidian Creek certainly reflects Yellowstone in its natural state—and so does the Firehole River!

What do the EPT species indicate about the water quality of Obsidian Creek at Sites 1?

Gray
In other words, the changes we witnessed in the Firehole are also due to contributions from hydrothermal features! No wonder the river's temperature increases—it flows through *three* major geyser basins! Just look at our data!

Farnheid
The thermal additions change more than just the river's temperature. Water from hot springs and geysers spends hundreds of years working its way through underground plumbing systems, eroding and carrying along minerals and elements, such as bicarbonate, chloride, arsenate, and sodium from the rock through which it passes. When thermal water empties into the Firehole River, these minerals and elements are also dumped into the stream. From the Upper Geyser Basin alone, the Firehole receives an estimated 68 tons of bicarbonate and chloride *every single day*! Your data shows that the pH level of the water rises as the stream passes through the geyser basins—this is largely due to the added bicarbonate.

Glossary
bicarbonate—a chemical that is a variety of carbonic acid salt; some bicarbonates are used as antacids

chloride—a compound containing chlorine

arsenate—a salt of arsenic acid

sodium—a soft, light, silver-white metallic element; when sodium is combined with chloride, the compound is known as salt

Does the Firehole River become more or less acidic?

Viola
Oh, don't be ridiculous! Three geyser basins can't affect the river *that* much! After all, they *are* really rather minor details when you consider that the stream flows for 30 *miles*, or 48 kilometers!

Farnheid
Let me give you an example of a single thermal feature called Excelsior at Midway Geyser Basin. Once upon a time, Excelsior was a geyser, though now it usually behaves as a bubbling hot spring that overflows constantly. In the 1950s, scientists attempted to estimate how much of this runoff entered the river. Their best guess was that between 3,000 to 4,000 gallons of thermal water poured into the Firehole—

Viola
So what? Three or four thousand gallons is *nothing* compared to the total volume of the river.

Farnheid
You didn't let me finish. Scientists estimated that Excelsior spills 3,000 to 4,000 gallons of scalding water into the Firehole River *every minute of every day!* I confess this is the first time I've ever heard Excelsior called a *minor* detail!

Where is Excelsior Geyser located?

Farnheid
The Lower Geyser Basin is another such detail. Hot springs line both sides of the river and the Firehole receives thermal runoff from such features as Ojo Caliente, Great Fountain Geyser, and the River Group.

Also, many tributaries of the Firehole are also thermally influenced and contribute additional hot water or chemical changes. By the time the river has finished its run through the Upper, Midway, and Lower Geyser Basins, approximately *a quarter* of its water comes from geysers and hot springs—and there's nothing minor about *that*!

Beadle
The famous trapper, Jim Bridger, thought the Firehole River was warm because the water flowed so rapidly across its bed that it was heated by friction. Now we know the real reason!

Farnheid
The Lower Geyser Basin marks the end of the thermal areas. After this point, the river starts to cool though it never regains its original temperature.

How much water in the Firehole River comes from geysers and hot springs?

Farnheid
We may learn a lot about how living creatures are affected in thermally polluted water by observing this naturally altered stream. In cases of thermal pollution, algae and other aquatic plants grow more rapidly—a factor which may upset the entire food chain! Greater plant density causes a reduction in the intensity of light in the stream. Less light decreases photosynthesis, which leads to a higher rate of plant respiration, depleting the water's oxygen supply. Most aquatic plants and animals need oxygen to survive and will drown if there isn't sufficient oxygen in the water.

Did you notice any differences in the microorganisms in the heated versus the unheated sections of the Firehole River?

Glossary
density—the number of individual organisms that are present in an area

photosynthesis—the process in which plants or plant-like microorganisms use sunlight to change carbon dioxide into cellular material and split water (or hydrogen sulfide) into byproducts such as oxygen (or sulfur)

How can a rapid growth of algae disrupt the food chain?

Gray
Yes, Maya said different algae were present at different temperatures. Diatoms were much more common in colder waters, and various types of green algae favored the warmer sections.

Maya
As the river's temperature increased, the amount of algae also increased. Then it declined as the water cooled slightly at our final sampling site. I didn't find this too surprising since very few species of algae are best suited to live in cold waters—and those that are don't seem to grow very quickly. Now, however, I understand another reason algae grow faster in warmer sections of the river. Algae need bicarbonates to grow and the thermal runoff provides plenty.

Glossary
diatom(s)—single-celled algae, whose shells are made of silica

Are most algae best suited to live in cold water?

Farnheid
Studies of the Firehole River show that the best temperature for algae to thrive doesn't change with the seasons. Rather, it remains close to the maximum temperature of a particular location during its warmest time of year.

Viola
So what?

Farnheid
Most of the time algae in the Firehole are not growing under the best possible conditions because the river is only at its warmest temperature in late summer. However, once the river reaches its maximum temperature, the algae immediately begins to grow faster.

This may help us predict the effects of thermal pollution on a stream. Imagine that on the coldest day of the winter, the temperature of a river in Indiana becomes hotter because some of its water is used to cool a power plant. Based on the observation I just mentioned on the Firehole River algae, what would you expect to happen to the algae in our Indiana stream?

What is the best temperature for algae to thrive in a particular place?

Maya
A lot of the algae would begin to grow at a faster rate and increase rapidly!

Farnheid
Yes, although light is another factor in algal growth, we're finding the effects of temperature may be even more important.

Viola
Oh, for goodness sake! Can't we talk about something besides algae?

Maya
Certainly—let's talk about bacteria instead! It appears bacteria also grow much faster in the heated portions of the river. That makes sense because more living algae also means that more algae die, which in turn increases the growth of decomposers, especially bacteria.

One of the threats of thermal pollution is that excessive decomposition lessens the available oxygen in the water. Less oxygen leads to the deaths of more plants and animals or their replacement with species more tolerant of these new conditions.

Glossary
decomposer(s)—something that breaks down or decays something

Why do bacteria grow faster in the warmer parts of the Firehole River?

Farnheid
The hot water additions into the Firehole River also bring more unusual bacteria into the picture—thermophiles! These microorganisms thrive in the extreme temperatures of hydrothermal features. Some are carried away from their natural environments with the hot runoff into the river. Although they can't grow or thrive in their new colder home, they drift downstream and are very useful indicators of the extent of the thermal additions.

Viola
I thought that's what thermometers are for.

Farnheid
Ah, but now we know that some types of thermophilic bacteria are widespread outside of Yellowstone in such things as water heaters or steam condensate lines. These "bio-indicators" are particularly useful because they allow scientists to observe two different types of human-caused thermal pollution: that which is caused by large amounts of warm water and that which is caused by small amounts of very hot water.

Glossary
thermophile(s)—microorganisms that thrive in extremely hot conditions

condensate—a product of condensation. Condensation is when a gas or vapor is reduced to a liquid or solid form.

bio-indicator(s)—a living creature whose presence indicates the existence of certain environmental conditions

What are thermophiles?

Maya
I see what you're getting at, Dr. Farnheid. You wouldn't expect to find thermophiles in the runoff from power plants because the water temperature is never hot enough. However, many manufacturing processes produce smaller amounts of scalding water and thermophiles could pinpoint the location and extent of such additions to a water supply. Just think, Vi! You thought nothing lived in the Firehole River, but these are useful, as well as interesting living creatures!

Viola
I wasn't talking about bacteria and algae—I was talking about visible animals!

Why aren't thermophiles found in the runoff from power plants?

Beadle
Then let's discuss aquatic macroinvertebrates. I observed more variety and greater numbers of insect larvae in the warmer sections of the river. Of course, I know that insect distributions are affected by more than just the water temperature. The river's sediment and the rate the water is flowing are other important factors. Now I realize the thermal runoff adds bicarbonates to the river which increases plant growth on the bottom of the stream. This means there is more food available and more surfaces for bottom-dwelling creatures to attach themselves.

Farnheid
In streams affected by thermal pollution, the respiration and growth rates of certain species of macroinvertebrates sometimes change, as well as their feeding rates and reproduction patterns. This dovetails with observations made here in Yellowstone. The macroinvertebrates in the thermally influenced waters of the park vary more in shape and size than their counterparts in cooler water—and some even experience changes in life behavior.

Beadle
What do you mean?

Glossary
respiration—the physical and chemical processes by which an organism takes in and uses oxygen and emits carbon dioxide

dovetail—to fit or coincide with

counterpart— a person or thing that closely resembles another

How are macroinvertebrates in streams affected by thermal pollution?

Farnheid
Most stream insects have an annual turnover—once a species hatches, the entire population disappears from the water in a short period of time and doesn't grow back until the following year. However, in thermally influenced areas, some of these stream insects are actually producing *two* times a year! For example, a certain caddisfly, which emerges from cold water streams in March or April, is also hatching from the Firehole River in November!

Viola
Oh, wonderful.

Gray
Doc, our Firehole investigation started when Viola DeRama expressed concern about the EPT species in Obsidian Creek. How do the Firehole EPT critters fare?

Beadle
I observed that many mayflies seemed to prefer the cooler areas of the river, while caddisflies were thriving in the warmer, bicarbonate enriched zones. Naturally, there was considerable variation within these groups. I didn't see certain types of caddisflies at *all* in the warmer waters, while several of the smaller-sized species of caddisflies were *only* found there.

Can stream insects reproduce in thermally influenced areas?

Farnheid
Although EPT species are important, the Yellowstone Ministry of Mysteries is especially interested in the New Zealand mud snail, another macroinvertebrate that prefers thermally influenced waters.

Viola
New Zealand mud snails aren't even native Yellowstone creatures! The fact that they're here at all indicates foul play!

Farnheid
No one knows how these animals came to Yellowstone, but we call them an invasive species because they've invaded this part of the world. New Zealand mud snails were first found here in 1994. Now they are in many of the park's streams—including the Firehole River. The mud snails are about one eighth of an inch or 2-4 mm long and live in dense groups on aquatic vegetation and rocks in stream beds.

Glossary
invasive species—a non-native organism that has intruded into an area and may have serious detrimental effects on native organisms

What are New Zealand mud snails called in Yellowstone?

Beadle
Isn't there concern the mud snails may out compete native macroinvertebrates?

Farnheid
Yes, in 2003, the mud snails made up between 25 to 50 percent of the macroinvertebrates found in the Madison River. In the areas occupied by mud snails, there were fewer native mayflies, stoneflies, and caddisflies. Our data also indicated the mud snails were abundant in the Firehole River *downstream* of the thermal additions, but almost nonexistent in the upstream portion.

Maya
Is this because the snails don't like cold water?

Farnheid
Maybe, but it isn't the only reason. Research has also shown that New Zealand mud snails can live in a wide range of temperatures. Their numbers and distribution may be limited more by changes in the river's water chemistry. Also algae, a major food source for the mud snails, are much more abundant in the warmer parts of the Firehole, as you observed earlier, Ms. Crowbes.

Glossary
out compete—to compete against in a manner that exceeds and may overpower

Why are there more New Zealand mud snails in the warmer parts of the river?

Gray
Do you know the effect of these invaders on fish, Dr. Farnheid?

Farnheid
It's not fully known, but studies indicate that the snails can pass through a trout unharmed, while offering absolutely no nutritional value. The snails crowd out native aquatic insect communities, which provide nourishment for fish. They also eat algae—another major source of food for fish. Anglers are asked to inspect their equipment, boats, and shoes for these aquatic invaders since it's very important to stop the spread of the snails into other waterways.

Glossary
angler(s)—fisherman

How can anglers help stop New Zealand mud snails from spreading into other streams?

Gray
Speaking of fish, I've read that when Yellowstone became a national park in 1872, the Firehole River had no trout.

Viola
Of course not! It's too—too thermally *altered*! The water in the Firehole may be okay for bugs and bacteria, but not for fish!

Beadle
Actually, there were no fish in the Firehole in 1872 because the central part of this park is a high plateau, surrounded by sheer cliffs and steep drops. These natural barriers prevented fish from entering waters that were otherwise livable. In the case of the Firehole River, fish were barred from moving upstream by the Firehole Falls. Rainbow and brown trout were introduced into this river in 1889 and stocking continued until the early 1950s.

Are rainbow and brown trout native to the Firehole River?

Farnheid
Our observations on the effects of hydrothermal runoff on fish in Yellowstone's waters are unexpected. Studies show the maximum recommended temperature for trout is 68° F or 20°C, yet these fish occur throughout the Firehole River—even in places where the water temperature is much higher than that limit.
Also, the thermal waters dump arsenic and other elements into the water. Although arsenic is poisonous to humans, rainbow trout thrive in areas of the river with the *most* elevated levels! Brown trout are rare in such places so it's possible these trout are more sensitive to certain elements or perhaps the temperature of the water deters them.

Gray
I bet that both the water temperature *and* its chemistry influence where different species of trout are best suited to live. I noticed there were few very young browns in the hottest parts of the river, so I suspect they don't reproduce as well there—at least this is true for many fish in areas of thermal pollution.

Can rainbow trout live in areas of the river with high levels of arsenic?

Farnheid
Good observation, Mr. Fischer. Also, in thermally polluted waters, warmer temperatures increase the metabolism of fish, so they eat more aquatic insects. At first a fish population grows, but eventually the food source is depleted, and there are problems in the food chain.

The Firehole River may provide us with a glimpse of how a naturally thermally influenced ecosystem has adapted over an extended period of time. While human caused thermal pollution may have begun a little over 100 years ago, Yellowstone's waters have been thermally influenced for tens of thousands of years. The waters of Yellowstone may provide a window into the future... a way to perhaps predict what might happen in other areas over time. We've observed that trout have changed some important life functions in the heated versus the unheated portions of the river. Those in the unheated areas feed on immature, bottom-dwelling insects—such as caddisfly larvae—while in the warmer parts of the river, they gulp down mollusks, true flies and mayflies, and feed mainly on winged insects, rather than on larvae. The warm-area browns have two annual growth periods and are much longer. Those from the cooler sections have only one annual growth period and are smaller. Mr. Fischer, did your group notice anything special about the rainbow trout?

Glossary
metabolism—the physical and chemical processes in which food is converted by an organism for the maintenance of life

deplete(d)—to exhaust the supply of something

mollusk(s)—an invertebrate typically having a hard shell that encloses a soft body, such as a snail or bivalve

How is the life history of brown trout different in the heated parts of the river?

Gray
We observed that there were more of them in the heated parts of the river.

Farnheid
Yes, like the brown trout, the rainbows in the warmer water are longer, have two annual growth periods rather than one, and have a similar diet. However, *unlike* the browns, the rainbow trout reproduce successfully in the warm sections of the river and have even changed their annual spawning time from spring to fall.

Maya
Isn't that odd, Dr. Farnheid?

Farnheid
Not when you consider the seasonal shifts in water temperature. At what time of year do you think the river is coolest?

Can rainbow trout reproduce in the warmer sections of the river?

Viola
Winter of course—Yellowstone is known for its long, cold winters!

Farnheid
Even so, the water in much of the Firehole River stays relatively warm year around. The coldest temperatures actually occur in mid June when the runoff from melting snow is greatest. The warmest period is in August when the snow melt has gone and the summer sun is heating the water. Therefore, the shift in rainbow trout spawning time serves two purposes—it avoids the highest temperatures of late summer and allows the young to grow throughout the winter before the river reaches its hottest temperature again. This means the fish are older before they have to cope with the stresses of high water temperature.

Gray
Why don't the fish take refuge in tributaries of the Firehole during the summer?

Glossary
tributary(ies)—a stream that flows into a larger stream or body of water

When is the water in the Firehole River coldest?

Farnheid
Often they do, but keep in mind that many of these tributaries are also thermally altered. At any rate, fish that have moved into tributaries return frequently to the Firehole River itself—perhaps seeking additional food. After all, plentiful food is one reason that larger wildlife also live around this river.

Beadle
Ms. DeRama, didn't you report seeing a bison named Rosie in the Old Faithful area?

Viola
Yes, but that has nothing to do with this discussion! Rosie wasn't near the river when I saw her—and there was plenty of food available elsewhere.

Why do large animals live around the Firehole River?

Farnheid
Nevertheless, the Firehole River Valley is important habitat for elk and bison in the central part of the park—especially during the winter. Grazers find food to eat and warm ground upon which to rest—which mean predators, such as wolves and bears, find plentiful prey!

The thermal runoff also provides habitat for ducks, geese, and swans. During the winter, sections of the Firehole River remain ice free. Waterfowl gather in these areas because they can find water plants to eat—maybe even with aquatic insects for spice!—and open water for their flight takeoffs.

Glossary
habitat— the environment in which life forms live and grow

predator(s)—an animal that survives by killing and eating other animals

How do thermally influenced areas of the Firehole River help waterfowl?

Maya
I guess the take-home message from our meeting today is very different from what we expected, Dr. Farnheid. The Firehole River isn't a damaged ecosystem—its natural alterations provide unique and critical habitats! The river may even serve as a living laboratory in which to predict the long-range effects of human-caused thermal pollution! Thank you for taking the time to talk with us about our concerns.

Farnheid
It was my pleasure. I'd like to express my gratitude to all of *you* for your attention and interest. An observant questioning public is very healthy for a national park, so please continue to visit Yellowstone, learn about its resources, remain curious, and keep your eyes open!

My door is always open if you have questions, Ms. DeRama. I want to encourage your interest, so please ask me about my work instead of borrowing it without my knowledge. In return, I promise I'll do my very best to level with you.

Viola
Well, I, uh

Gray
Saved by the bell!

Is the Firehole River a damaged ecosystem?

Viola
Oh, excuse me, everyone. That's my cell! *Of course* I can talk now—we weren't discussing anything important at all. You say you've uncovered a new plot? *What?* Oh, that's the most ridiculous thing I've ever heard—*don't* be absurd!

Farnheid
May I ask what that was all about?

Viola
One of my researchers thought he had uncovered a plot at Yellowstone National Park. He said our discussion today was going to be broadcast on the Internet—which is sheer nonsense, of course! It's almost as bad as that wild story he tried to sell me on the other day. He was convinced—*absolutely convinced* that the Firehole River was in serious danger from industrial pollution, when it's *obvious* the river is naturally altered by thermal runoff. *Some* people will believe anything!

Has Viola learned her lesson?