SHOW 103

EPISODE OPEN

NARRATION Killer whales, the ocean's greatest predators, they just won't stop talking. Listen in while Scientific American Frontiers. Also a new cure for brain tumors--it takes, just twenty minutes. Glaciers of the Swiss Alps. What's going on inside? The battle of the water balloons between teenage scientists. And a life-and-death battle on the forest floor. All coming up on Scientific American Frontiers.

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WHALE TALK

WOODIE FLOWERS Hi. I'm Woodie Flowers, host of Scientific American Frontiers. We have just been running through some scuba-diving signals down there. This one means "watch out for the shark." This one doesn't mean "it's too late the shark just got me." It actually says, "I'm running low on air." You know, wherever we go we take along the need to communicate. Under water, a language is very primitive. Divers are restricted to just a few dozen signals. Most are concerned with survival. Of course, there are plenty of creatures that are much more at home in the water than we humans. And some of them seem to communicate all the time. Is it just survival that's their concern? Could it be something else?

NARRATION It's early August in the Puget Sound. Every summer the orcas or killer whales, return to these sheltered waters off Washington state. For many years the whales have been photographed and observed by Ken Balcolm and John Ford. There are 85 orcas that enter the sound. And for Ken Balcolm, they provide a subject of endless interest.

KEN BALCOLM I personally am fascinated by their social behavior and their very apparent intelligence. I wonder what's going On in that huge brain of theirs.

NARRATION Orcas are so well organized they can take on anything -large whales, sharks, whole schools of salmon.

KEN BALCOLM We've got a foraging pattern. Probably have some fish under about 60 or 90 feet down that are ahead of them. And they are just keeping track of them. They probably have already eaten. They are just not going to let them get away. They will follow them for the rest of the day and then when they are hungry they will eat some more.

NARRATION The biologists have learned to recognize every whale in Puget Sound. Dorsal fins are one marker: females have short ones, and males, they are twice the size. Some fins have odd shapes. This wavy one belongs to a male from J Group, or J-pod, as it's called.

KEN BALCOLM We just saw J-l, the one with the wavy margin to his fluke, his fin. J-3 bent over about halfway up. J-5, J-17.

NARRATION They have discovered a whole catalog of distinctive marks. This big male is J-6. He's got pieces missing from the back of his dorsal fin. This female acquired a clear nick out of her fin, as did this one. They're minor wounds picked up during rough play when the whales were young. And they have all been recorded. Ken Balcolm can recognize most of these white markings too. They are called "saddle patches." So now he can keep track of all the whales in the three pods that use Puget Sound.

KEN BALCOLM Who do we have here? Just Ks maybe?

JOHN WARD We got K-1. Two notches. Good indication of K.

KEN BALCOLM No, you can't mistake him. in here? What else have we got

JOHN WARD K-17. There he is.

NARRATION The identification system has become the key to understanding whale behavior. And Ken's discovered that orca pods stick together--for life.

KEN BALCOLM Now here is the new one. K-21.

JOHN WARD Oh yeah.

KEN BALCOLM And it's traveling with K-187

JOHN WARD Yeah, it's right next to its mother right there.

KEN BALCOLM We see a new calf. And it's right next to its mother. We know it's its mother because it's always right next to its mother. And we see it nursing from its mother. So we can tie that one in. And then we watch that calf grow up. Two or three years later, it has a brother or a sister. And then that one is the one that's next to her. But the other one still stays alongside, but not as closely.

NARRATION Today they are getting ready for a recording session. It may seem like a quiet day on the surface, but under water, things are different.

KEN BALCOLM Yes, they are chatting all right. The S-2 called and a couple of S-Is. So, you can confirm the ID?

JOHN WARD Yes, definitely Js. No doubt about it.

NARRATION The challenge now is to try and relate whale behavior to whale calls.

KEN BALCOLM Each pod has about a dozen really stereotyped calls that they use over and over again. And these different calls can sound quite different from one another, within the repertory of calls. Some might be sort of a squawk and others might be quite a elaborate squeal with an upsweep on the end.

NARRATION The scientists spend long hours studying computer voice prints of the calls.

JOHN WARD J seems to have that really distinctive down sweep on the end, so each call seems to go up and then ends on a down sweep. So you can see that one--S-3.

NARRATION This call is only used by J-pod.

KEN BALCOLM Next is L. We'll just listen to some Ls and their...

NARRATION This one only L-pod uses. If each pod stuck to its own call, they might just be recognition signals. But it seems pods share calls.

KEN BALCOLM There's the J version of call S-2.

NARRATION Take this call. J-pod uses it like this. And L-pod uses this modified version. John Ford's discovery of these dialects, as he calls them, has added a new layer of complication and mystery to the study of orcas calls. And it's led to an unusual laboratory: Sea World in San Diego. The Orcas learn their tricks and they also keep right on calling. Biologist Ann Bowles.

ANN BOWLES There are several questions that we have not been able to answer in the wild. The first is, how did the calves develop their calls? We can't isolate a calf from other whales in the unit to be able to determine even what a calf call sounds like. So here in captivity we have the unique opportunity to watch the individual separated from its mother and other whales, see how it behaves to find out how long it takes to develop adult calls. And all this kind of very basic information.

NARRATION There are three whales in this pool: two adults and one two year old.

MAN This is Corky and she's from the Puget Sound area, in the Pacific Ocean. This is Kassatka, and she is from off the coast of Iceland. And then that is Orkid, and she was born right here, at Sea World.

NARRATION Two years ago, as the Sea World cameras rolled, everybody waited in suspense for the moment of Orkid's birth. What nobody knew was that an extraordinary experiment was about to begin. Like her wild cousins, Orkid kept close to her mother. She heard her mother's calls and she picked them up.

WOMAN Well at one year of age she was making still kind of baby babble, but those calls that were discrete were very much like those of her mother's. And she would give these in sequences of calls with her mother, as though she were imitating her mother.

NARRATION And then soon after Orkid's first birthday, her mother died. She started swimming with companions unrelated to her, whales that used different calls. So suddenly there was an experiment going on in the Sea World pool. The question was, would Orkid learn new calls? There were certainly plenty to choose from. Now, one year after Orkid was orphaned, it's time for Ann Bowles to find the answer.

ANN BOWLES O.K., the hydrophone is about two meters down and a meter and a half away from the acrylic panel number one. And we are waiting for the calf to come by. Orkid is swimming around, close to the hydrophone. Now there's a call. Orkid. And I can hear her response in air from Kassatk behind. Super.

NARRATION Ann Bowles recognizes all the calls in the pool, including those from a whale called Kassatka.

ANN BOWLES I'm finding exactly what I thought I was hearing out there which is that they are calling back and forth to each other. This is a very typical Kassatka call right here, very classic. This sequence here is Orkid first, Kassatka second, Orkid buzz with upsweep, Kassatka, buzz with upsweep--imitating each other. And Orkid is using Kassatka's call.

NARRATION It means that killer whales aren't locked into using standard calls that they inherit. But they wouldn't need this learning ability or their dialects just to recognize each other, or even to round up salmon. John Ford believes the whales are much farther along than that.

JOHN WARD In humans, the ability to, to learn sounds is the key to the development of languages. And it may be the key to the development of potential languages in the whales. I don't believe that they have the sort of language that we do. But they must be on some point along that road towards a true language. And I think the dialect system of killer whales is a very good indication that they are progressing towards that stage.

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3-D THERAPY

WOODIE FLOWERS Our next story is a medical one. We often do medical stories on Scientific American Frontiers because there is no other field where the direct benefits of science are so obvious. But medical stories are sometimes difficult to cover on television because they can be painful to watch. I want to warn you that there is something in the first minute of this story that looks painful--although it really isn't. So please stay with the story. Close your eyes for a moment if you have to, and you'll find out how one branch of medicine is making some major advances in helping one particular patient.

NARRATION Ken Walkerhas a brain tumor. But the chances are that by the end of tomorrow a new kind of radiation therapy will have killed the tumor--in a single treatment.

KEN WALKER Initially when the doctor said, would you like to try it, I said "Absolutely!', The traditional radiation would probably be every day for six or seven weeks, which is kind of from a life, going on with your life, difficult to work in. This has the possibility of being a one-and-done, so it sounds great to me. I'm all for it.

NARRATION Eight A.M. the next day, at Boston's Brigham and Women's Hospital. It's a startling scene as doctors prepare to attach a metal ring to Ken's head. It's essential for the ring to stay in position throughout the day, so they'll use blunt plastic pins to tightly clamp the supports to his skull.

DOCTOR Mr. Walker, right? This is the worst part of the day.

KEN WALKER It may look like medieval torture, but Ken feels no pain. In fact, the little lumps on his forehead are filled with a liquid pain killer.

NARRATION Neurosurgeon

EBEN ALEXANDER developed this treatment, along with radiation therapist

JAY LOEFFLER on the right. They wii1 use the ring and this metal cage which fits onto it to find the exact position of the tumor. Eight-fifteen A.M. Ken is going to have an x-ray called a CAT-scan.

DOCTOR Ken, now don't hold your head. Relax. Relax your neck.

NARRATION It's routine for most large hospitals, but here the team will add a special feature. As Ken's wife, Gloria, looks on nervously, the metal cage has been fastened securely to the ring. Now it will show up on the x-ray, and provide fixed reference points for precisely locating the tumor. It's like putting a grid of lines on a map to allow a map reference to be read off. The x-ray procedure begins. In twenty minutes the machine will take a series of pictures through the head. The pictures are arranged in slices an eighth of an inch thick, piled one above the other, like the floors of a building. The tumor shows up as a dark shadow just behind the left eye. It's clear to the doctors, and to Ken's wife.

DOCTOR We'll probably target a little bit off center.

NARRATION With these pictures the team will work out the exact shape, size, and location of the tumor, and then plan the therapy. The planning is going to take several hours so now for Ken comes the most difficult part--just sit and wait, with the rings still in place. It's the vital reference point needed for the treatment later today. The team moves over to the computer system at the nearby Dana Farber Cancer Institute.

EBEN ALEXANDER begins work.

EBEN ALEXANDER Right now what we're doing is just marking in the contours as we see them here, of the tumor itself. What this enables us to do is to come up with a three-dimensional reconstruction in space.

NARRATION Eventually the computer will have a complete picture, not only of the tumor but also of the eyes and other critical structures nearby that the treatment must avoid. Here the optic chiasma--the delicate structure where nerves from the eyes join together--is being mapped. And here they are marking out one of the optic nerves, another critical structure. After three hours spent marking out every x-ray picture, it's clear that the tumor is dangerously close to two crucial structures. They have got to be left unharmed by the treatment.

EBEN ALEXANDER So here is our real challenge. It's right here. Because here we have the tumor itself and then immediately within four to five millimeters away is something that we don't want to give any radiation dose to. The tumor we will get maximum dose to. And the optic nerve and chiasma, very low dose.

NARRATION It's two in the afternoon. The planning session is now being led by physicist Hanne Kooe. It's his job to work out how to safely direct the radiation at the tumor, using this three-dimensional computer map. It shows the tumor in blue, and close by, the crucial structures, all precisely located above the circular metal ring which Ken is still wearing. If Ken were going to have conventional radiation treatment, his entire head would be given a small but damaging dose every day for a couple of months. It only works because the healthy parts recover more quickly than the tumor, which gradually dies. In contrast, the new treatment will use concentrated beams of radiation directed just at the tumor, possible only because they can fix its position so accurately. A single treatment will kill the tumor. In the planning session they are now trying out different pathways for directing the radiation beams at the tumor. The computer keeps track of places where a beam would pass through a critical structure. And it becomes clear that getting enough radiation in to kill the tumor will inevitably means some exposure of the optic nerve.

HANNE KOOE At this point we have to decide, given those set of beams and placement of those targets, what is the actual dose we will be delivering to the tumor, and what is the actual dose that we will be delivering to a critical structure.

NARRATION Here the computer shows in red the high-radiation dose area. The tumor is covered but so is a small part of the optic nerve. There will be some damage--but not enough, it's judged, to harm Ken's vision. It's now late afternoon. And the constant pressure of the ring has given Ken an excruciating headache. It's turning into a very long day.

GLORIA WALKER Well it's real harm to look at him like that. The lights on. I'm not real good with needles or anything like that, so I always have to look away with IVs or anything. So this is not a real pleasant visual appearance.

KEN WALKER This morning I, the anxiety had to do with putting this contraption on. And I'm not at all anxious about getting the radiation treatment. I'm just anxious about getting this thing off.

NARRATION Finally, at six o'clock, it's time for the treatment. The ring is locked into position. Now the tumor inside Ken's head has become a precisely located target, that the beam from the radiation machine will be able to reach with pin-point accuracy. There's a quick run through of the moves which the team spent the day planning. Then it's back to the control room for the real thing. There'll be just twenty minutes of exposure.

WOMAN 2.91 going to the ...

NARRATION Ken will avoid entirely the unpleasant side effects which would go with conventional, long-term radiation treatment.

EBEN ALEXANDER When he leaves that room, the tumor has been altered in such a way that it is now essentially dead. So this has a very dramatic effect on the tumor, and just with this one twenty-minute trip into that room, we are going to kill the tumor.

NARRATION The treatment itself is virtually automatic: except for the tumor, nothing is going to change now. But somehow it doesn't seem that way.

GLORIA WALKER It's probably just that nerves are a part of the whole thing. Just waiting and knowing that it's really going on. That this is the whole reason why we came here. So, I'll be glad when it's all over.

NARRATION It quickly is. Now the moment Ken's been longing for.

EBEN ALEXANDER Take it easy for a moment. O.K.

NARRATION Relief, though, is not immediate. He's got the worst headache he's ever known.

KEN WALKER One of the problems with the frame when it's on all day is that you get used to it being on. And when you release the tension of it, it's, that's the worst time for the headache. And this kind of pressure headache will go away very quickly.

NARRATION And the next day Ken had no problem keeping an appointment with our cameras.

KEN WALKER Just after I got the ring off I was feeling pretty poor, but within, I guess the doctors said within an hour or so, most of it would go away. By the time we got down and got the taxi, got back to the hotel, I felt good enough to go downstairs and eat dinner.

GLORIA WALKER It's a good feeling to know it's all over and done with and it was successful and he's feeling better and all one piece. And it's great.

NARRATION There are just a few places in the world where this kind of high accuracy treatment is possible. But for

JAY LOEFFLER, that won't last long.

JAY LOEFFLER We're tired of having long-term complications to radiation. You have to be more specific--get in the radiation to where tumors are, and avoid normal structures on the way in and out. I think this is just the beginning of a lot of changes in radiation therapy.

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INVASION OF THE PUPAE SNATCHERS

NARRATION It's a sunny Tuesday afternoon in the Chiricahua Mountains of Arizona. And there's a strange group of people who are looking for something.

DR.HOWARD TOPOFF We’ve got a colony-with the queen and brood! And, but she got away. But she certainly was onto the rock.

NARRATION Yes, believe it or not, this is a hunting trip for ants. Howard Topoff and his students at the Southwest Research Center know exactly where to find them--which is about everywhere. But they are after just one particular kind.

DR. HOWARD TOPOFF The vast majority of ants can take care of themselves. But a small group have lost all those abilities. They become parasites. They can't get any food for themselves, they can't clean their nests, they can't feed their young, they can't feed their queen. The only adaptation they seem to have left is the unique ability to get other ants to do all these jobs for them.

NARRATION And these are the crafty parasite ants. They are called Polyergus, red in color, about a quarter inch long--and ruthless. The Polyergus parasites are good at just one thing: making war.

WOMAN Howard, they're raiding.

DR.HOWARD TOPOFF There they go. Up here.

NARRATION Practically every afternoon, not just Tuesdays, the parasite ants send out their armies. As the marauding hordes stream over any obstacle, other ants in the forest are cowering in their nests. Who is going to get hit today? The parasites have found their target. The first innocent victim is slaughtered. And it's always these peaceful Formica ants that are attacked. Now the raid is in full swing. Quick as a flash the parasite ants climb down into the nests and haul out the living white pupae of unborn Formica ants. The red parasite rush their booty back across the obstacles into their own nests. And inside is the most amazing sight. It's full--not of red ants, but of their victims, peacefully looking after red-ant pupae, as well as their own. Today's raid has brought more victim pupae, ants that will be born into slavery. In his lab Howard studies this strange relationship. The victims are well armed. They give off poisonous formic acid. So do the red Polyergus parasites. But look at what happens when the two types meet. In this test they will be kept apart with a wire mesh, but they can still use their chemicals on each other. The result is always the same: even though they both have the same weapons, it's clear that the Formica victims are not doing well out of the exchange.

DR. HOWARD TOPOFF After just a few minutes, all the Formica workers are dead and all the Polyergus workers are still running around. This suggests to us that the Formica workers are indeed sensitive to this noxious chemical formic acid. The couldn't care less. They seem to be virtually immune to it.

NARRATION The parasites are unbeatable. And they're superbly organized too.

DR.HOWARD TOPOFF This scout has just begun scouting. It's kept a relatively straight line from the nest, moving in a southwest direction. It hasn't even started to lock for nests yet.

NARRATION Every day parasite scouts move out in different directions to look for victims. Now this one is about a hundred feet out.

DR.HOWARD TOPOFF She starts circling around, making loopity loops, running in a kind of a tortuous path. Now she's actually looking for Formica nests. And as she moves she sticks her head, sort of pokes her head underneath rocks and leaf litter, and underneath fallen logs.

NARRATION There's a quick fight when a nest is located. The inevitable outcome. And then back runs the scout to call out the troops for a raid. But not so fast. bigger than you. If you're an ant, there's always something There'll be no raid today. It occurred to Howard that it was not just spiders that could stop the raiding. He's mixing up some honey water. And he'll place it where some Formica victims will find it.

DR.HOWARD TOPOFF I'm putting the honey water down on the ground where there's a trunk trail of Formica workers. They are going back and forth, looking for food. And it will take but a minute for them to find the honey water and they'll probably start to recruit nest mates within a couple of seconds.

NARRATION Remember: these are victim ants. They work for the parasites, and feeding their masters is one of their tasks. Very quickly they clean out the dish of honey water and then they will head back to the parasite ants' nests, their adopted home. Inside the nest they regurgitate the honey water and feed their masters. Table manners aren't a big thing in the ant world. There was one striking result of Howard's feeding program.

DR.HOWARD TOPOFF We find that if we keep feeding the Formica workers over a period of several days, slowly but surely the number of raids starts to decrease in frequency. And it remains low throughout the entire summer. So what we have learned from this experiment is that the Polyergus raids are at least in part motivated by hunger.

NARRATION So when the parasites steal pupae, they get new workers--and food. But for parasite ants, perhaps the biggest challenge is starting a new nest.

DR.HOWARD TOPOFF In most of this species of ants, the queen, after mating, digs a little hole, lays a few eggs, and when those eggs hatch into larvae, she feeds them. But a Polyergus queen is kind of in a unique situation because she is, after all, a parasite. She can't take care of her own eggs. She can't even take care of herself.

NARRATION This is a Polyergus parasite queen. She is being released near a Formica colony, so far undisturbed by any parasites. The Polyergus queen is peacefully laying eggs surrounded by her attendants. Almost immediately, Formica guards rush to attack the parasite queen--but it's no use. Then the parasite queen pulls an astonishing trick. She plays dead, and allows herself to be dragged into the nest, as if she were a piece of food. By now the threatened o~ queen has retired to the corner, but her attendants don't seem to realize the mortal danger. Suddenly the Polyergus parasite queen reveals her true identity. There's panic in the nest. She rushes to attack her target--the hapless Formica victim queen.

HOWARD TOPOFF The fight between the Polyergus queen and the Formica queen is very, very prolonged, very, very brutal, and very, very intense. We think that the Polyergus queen, by continuously biting the Formica queen, is perhaps getting some of the chemicals that identify the Formica queen as a queen. She covers herself with them. That may be why the workers of the Polyergus queen eventually treat the Polyergus queen as their own.

NARRATION The battle royal took over fifteen minutes--but the Formica queen was doomed from the start. She's dragged away by her own offspring, who have become a peaceful new nest of victims, ruled over by the parasite queen.

FLOWERS They are tropical carpenter ants, like the kind that will chew up your house if you are not careful. Now listen. Know what they're doing? They are actually banging their tails on the floor. And like the killer whales in our first story, they are communicating. That's what Norm Carling at this lab here at Harvard has figured out. He thinks they are saying, "Trouble. The nest has been disturbed." He thinks that because right after the alarm is sounded, every single ant starts putting the nest back together. Ants don't just use sound for communication. It's more common as the ants and other insects use chemical messages. Like the parasite queen in our story. She fooled her new victims with a chemical lie that announced that they should now serve her. Actually, that's a good example of the kind of odor trickery that's beginning to serve a very useful purpose. It can provide new ways to control pests without using large doses of environmentally-sensitive pesticides.

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JUST ADD WATER

WOODIE FLOWERS School's out at Saguaro High School in Phoenix, Arizona, and it's practice time for the Science Team. They're in heavy training for the National Science Olympiad, just three weeks away. Today it's a rigorous test on the behavior of water balloons. It's the key to a challenge issued by Scientific American Frontiers.

GIRL We don't have to exert this untenable force ....

NARRATION And the forces involved will become quite important as they begin their mission. The challenge is to build a machine to move water out of this space. The water must start in a balloon, but somehow be released into a funnel ten feet away. Time limit--one minute. Weight limit--22 pounds for machine and water. No electric power allowed. Saguaro is just one of dozens of schools across the country developing different solutions to the challenge. Andy and Julie have built this test vehicle. They are using weights to simulate the water.

ANDY Kind of like a little windup car where you pull it back and let it go.

NARRATION They have concocted a unique drive train.

JULIE When I pick my mass up here, it wants to go down because gravity is acting on it. It wants to fall. And that falling of it will spin the axle, as it's wrapped around there, and cause the car to go.

NARRATION Time for a test.

JULIE Perfect.

NARRATION The results are encouraging.

JULIE This is great because you only want to kind of leave it, take more work and now you are taking more potential energy, so we can even put more mass on it than we have now.

ANDY We're going to go for maximum capacity. And we'll get to a certain point where we can say, o.k., this is too much. This is too little. This is just right. Kind of like the Goldilocks story, you know, maybe we'll end up with a happy ending.

NARRATION But getting it just right isn't easy. There's so much to worry about.

JULIE This string didn't make it.

NARRATION But mistakes are all part of it. Coach Tom Vining.

TOM VINING You get to hear ideas in minds that are fresh. Most of them are not trained engineers by any means so they are working on the trial-and-error system. Build it, see how it works, and then go back. Kind of like the Wright Brothers.

NARRATION Across the country in Greensboro, North Carolina, the Page High School team is perfecting a very different machine. They have decided to keep the balloon at the start, mounted in a water tower. This way they can put the weight into the water, not the machine.

TOM VINING It's hard to build a vehicle that's going to carry a large amount of water. And this, you know, we can get a lot of water there without a lot of weight.

NARRATION The key is this plastic hose which will be unrolled by the water itself. And to get it flowing, a pin triggered by a mouse trap which will also release this bridge that directs the hose toward the funnel. The trigger works great. But that's about all.

GIRL It worked, yeah!

NARRATION More work for the team.

BOY I'll do it over again.. Well, every time you fail, then you have got to keep it going

BOY Do it all over. See if you can improve it in some way, if possible

BOY #2 What I think happened was that as the bridge was coming down, and the bridge was still coming down, the water got to the coil. It was just the coil didn't have any, it couldn't go this way. It popped off the side.

NARRATION Can they get things going in the right direction?

BOY Don't touch it if we can avoid it.

BOY #2 Oh, oh, it's going to work.

NARRATION The scheme has got a lot of promise. BOY If the stand weighed nothing, we could get about 3.1 gallons. So if we can get two and half, somewhere between two and a half and three gallons in, we'll be doing good.

NARRATION There's more work ahead to improve reliability, but it's already worth the effort, according to Blythe.

BLYTHE It just starts out ... and it works. And then it's just getting more and more refined and then it gets working more and more often now. And it's exciting.

NARRATION That excitement reaches a peak as 2000 students descend of Pennsylvania's Clarion University. Fifty teams will compete. Everyone is raring to go. In their motel, Saguaro High unveils their finished vehicle. There is now a strong nylon thread and a huge water balloon. Julie and Andy have loaded it with two gallons.

JULIE Basically the balloon will drop and it will pull it. The car coach, and as soon as it falls in the ditch...Oh my!

NARRATION Two gallons--that's a lot of water.

GIRL They are going to hate us here, they are going to hate us here.

NARRATION It's competition morning. Time to weigh in. A few last-minute adjustments. And some aerobic stretching before filling up. The first contender is a car from Colorado which uses an elevated ramp to pick up speed. The car works--but there's a problem. BOY We got up to the top but it was splashing over. There's a clog in the drain ....

NARRATION Many teams opt for long arms, but the thin tubing on this one yields only half a liter, about a pint. For better flow, this team uses wide tubing.

BOY#2 I don't think so. That's just right.

NARRATION They hit the three-liter mark, nearly a gallon.

BOY It's coming. I'm happy!

NARRATION Arms and tube machines, however, are complicated.

BOY #2 Which will cause this to close. And that will go straight out.

NARRATION And prone to breakdown. Some just don't get there. Some trip on their own tubing. And for others, it's just a simple twist of fate. Arms are unreliable. Cars are better. Here's Saguaro High. They take the lead, delivering a gallon and a half.

GIRL That is great! It worked!

NARRATION But waiting in the wings is South Carolina's Irmo High, a powerhouse team. They've entered two different machines. The first uses a hose truck.

BOY What we are going to do is we are going to release the ramp. The car is going to go down the ramp and into the funnel. And once it gets there, the balloon is popped. The water goes through the hose, into the funnel.

NARRATION Its light weight allows a large water load. They're ahead of Saguaro with over six liters--nearly two gallons. Irmo's second machine uses the same tower design, but a more complex delivery system--a catapult powered by rubber bands will send a hose flying over the course. There's a balloon-popping mousetrap. And the end of the hose is weighted to help it fly the distance. Watch how it works in slow motion. First, a bridge is released which rolls out on a castor, guiding the hose. A string attached to the bridge triggers the catapult. Finally, a second, longer string on the right triggers the balloon popper. Two and a half gallons! So now it's Irmo High first and second. For many machines a basic problem keeps popping up. But for others, things happen before they should.

GIRL I hate this!

NARRATION And some designs are having trouble going the distance. The designer of this car has built in more than enough power to get up the ramp and into the funnel. It's a leak back at home base that's his downfall.

BOY Well that's where the rubber gasket fell out.

NARRATION Page High School is up next. But they are still having problems aiming the hose.

GIRL The bridge, oh it's loose. And it can land all different ways, and we should have fixed it but we don't have time now.

NARRATION They line it up.

GIRL Yes. That's it.

NARRATION The bridge works. And makes them a top contender with over seven liters. Two gallons.

BOY We had to get the bridge ... right, to be able to decide that it worked.

GIRL Practice. We're all practice. Patience did it.

NARRATION Time for the top four teams to run off in the finals round. It's between Saguaro's water-carrying vehicle, Irmo High School's hose truck and Irmo's catapult, and Page High School's rolling hose. It's a closely-matched field. Irmo's catapult draws the first run. Reliable and effective. Two gallons--seven liters make it. Page High could beat that. There's two and a half gallons in their water tower. But it's the old problem--aiming the hose. Irmo's hose truck is next. And they top their own team's other machine, the catapult, with two and a quarter gallons--eight and half liters--to take the lead. So it's up to Saguaro's vehicle. They've loaded it with three gallons--right up to the weight limit. They've never tested so much. But it's the only way they can now win. But friction from the increased load stops the machine only inches from victory. The champion is Irmo High School's unstoppable hose truck. It's been a hard-fought competition but that hasn't interfered with the fun of it all.

GIRL This has been a blast.

BOY It worked. At least it worked once. Got us into the finals!

NARRATION You've got to make things work--and not just on paper, but in the real world. That's what the contestants found out.

GIRL It makes everything real. It's something that I'm doing, I'm not just hearing about it. I'm, I'm doing it myself. I'm experimenting and if I am wrong, I change it. And it's like real life. And so, it's really, probably the most exciting thing I've ever done in high school.

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FROZEN ASSETS

WOODIE FLOWERS For the contestants in that last story, water was the source of a lot of laughter. But also the source of energy to power most of their machines. Usually though, water power works more like this. O.K., here goes. As the water trades height for speed, it spins the homemade turbine wheel, which runs the little generator in the middle-voila! We get electricity. Aside from the bits and pieces of hardware, there are just two things that you need to do this--some water and some height. And we just used about fifteen pounds of water falling about nine feet to make a few watts of electricity for a few seconds. Clearly, if you want a lot of electricity, it would be nice to have a lot of water and a lot of height. Well, there's at least one country in the world that has both.

NARRATION Switzerland. It's summer time and the tourists are enjoying themselves. Most people spend their time down in the valleys, where the towns and cities are. Or perhaps there will be a little hiking on the lower slopes. At 10,000 feet up, it's a different world. Even in summer this is rugged and inhospitable country. But it's the ideal time of year to see the one unmistakable feature of these mountains--glaciers. You are looking at a stupendous block of ice. it in this one section. There may be about 15 million tons of There are dozens of them in the Swiss Alps, filling up the high mountain valleys, looking as solid and timeless as the mountains themselves. But, as these British scientists are discovering, glaciers are constantly changing. Martin Sharp leads the group.

MARTIN SHARP What I see is effectively a large river of ice which derives its nourishment from the snowfall which accumulates directly on its surface during the winter. And from snow which is transported from the slopes around it in spring and early summer by avalanches. Now as that snow accumulates on the surface of the glacier, it compacts under its own weight. It's compressed and it's gradually transformed into glacier ice.

NARRATION This is the scientists' second summer on the upper Arolla Glacier, not far from the famous ski resort of Zurmat. Here the glacier is disguised with a thin gray crust of rocks and pebbles, but underneath it's ice all the way down. Just how deep the scientists are now measuring. They'll use a depth sounder that bounces sound waves off the bed rock underneath the glacier to gauge the ice thickness. The Arolla is about four miles long, and here at the two-mile mark, the ice is at its deepest--over 700 feet. The Arolla would be a much simpler thing for the research team to study if it weren't for one awkward fact: when summer comes, the ice begins to melt. That's why, although the glacier is moving slowly, it never gets anywhere. In fact, it's gradually disappearing. The surface of the glacier becomes covered with an ever-changing network of little rivulets and rushing streams. And there's another complication. Right down at the lower end of the glacier, where it's completely covered with rock falls, the melt water ends up in a series of rivers. But the water doesn't flow off the top of the glacier. Somehow it emerges from underneath. How does it get there? That's one question that fascinates the scientists. And it's also something the Swiss people are very interested in too. This is the reason. It's called the Grand Dixence Dam, and it's the highest altitude dam in the world. The lake is 7000 feet above sea level, and it's made up entirely from glacier melt water. Project engineer Albert Bezinge.

ALBERT BEZINGE The glacier is like a bank account for Swiss hydroelectricity. Switzerland is the water capital of Europe. And the glaciers are solid water banks which melt and yield interest in the summer. That interest is the water which is collected in the lake.

NARRATION So much water so high up couldn't be better for generating electricity. It's fed down from pipelines to a series of power stations which provide a fifth of Switzerland's entire power needs. There's only one problem. The Swiss need most of their power during the winter when the glaciers are frozen solid. So during the summer melt, they have to concentrate on collecting as much water as possible. And that's where the research team might be able to help. On a typical day team members are spread out down the glacier. This is Keith Richards.

KEITH RICHARDS I'm measuring the discharge of the river so that we can see how it relates to the rate of melting on the glacier. And the water is freezing. Well, almost.

NARRATION Sharp. But cold feet are the least of their problems. Martin Sharp.

MARTIN SHARP The water doesn't run off from the glacier as soon as it's actually produced by melting. It has to find its way through the glacier by some sort of drainage system. And that draining system has to develop through the year as water is put into it. So what we are trying to do here is to understand what drainage systems within glaciers look like, and how they change through time.

NARRATION And that's turned out to be a very tricky question because of this: The glacier is covered with holes. A team member is preparing to investigate one of the hundreds of drainage holes that come and go during the season.

MAN How long has this site been opened?

MAN #2 Been opened for just over a week.

NARRATION At a pre-arranged time, he pours in a batch of red dye. It's biodegradable so it won't contaminate the stream. Meanwhile, in the valley below the glacier, other team members are setting up to sample the water flowing down. The hose is connected to an instrument that very accurately measures the color of the water. They will be able to detect any red dye that passes, even though by now it will be too dilute to be seen by the eye. In this case it was two hours before any dye arrived. And it took twenty minutes for that single release to run past. The water had somehow been caught up in the glacier's internal structure, and then slowly released. What's going on inside the glacier? Inside it must look like this--a series of large cavities, probably formed where the ice contacts the uneven bedrock. Connected by small cracks in the ice, the cavities trap the water, slowing down its flow. It sounds simple enough, but this drainage hole, lower down the glacier than the first, is going to produce a completely different result. The dye disappears into the glacier. And at the same point down the valley, the measuring team is in position. But this time the dyecomes past almost immediately.

WOMAN 451, 6.3.

NARRATION It arrives within ten minutes of release, and it runs past in just two minutes. Levels drop back to zero and then they pick up again for another couple of minutes. The water had drained out rapidly. There must be free-flowing channels--at least two different ones to account for the double pulse of dye that appeared. After running hundreds of tests, the team is pretty sure they know what's happening.

MARTIN SHARP All we find at the beginning of a melt season in the spring is that we have a short system of channels at the bottom of the glacier and then a cavity system above that. Now as the season progresses, the cavity system is gradually converted into a channel system. So we find that the channel system grows progressively upwards here and eliminates the cavity system.

NARRATION And that's a finding that's not just of interest to the research team as they hike through the mountains. To collect the summer melt water, Swiss power engineers have built a series of catchments where the glacier runoff drops down through grids like this. The water enters an elaborate network of pipelines and tunnels, 150 miles of them, carved into the mountains. Water from 38 different glaciers finds its way through the network into the storage lake behind the dam. Running the system efficiently is a constant headache because the water flows change all the time. So as the team learns more about how glaciers work, the engineers' job should get easier.

WOODIE FLOWERS The research team now has a pretty good idea of what goes on inside the Arolla. And it's a good thing they figured it out in time. At the rate it's melting, it will be completely gone in about a century. Well, that is, of course if it never snows again in Switzerland. Which is not very likely. In fact, the Arolla will still be around when the next Ice Age arrives. Stay tuned--it's due in about 15,000 years. That's all for today. See you next time for Scientific American Frontiers.

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